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• MTT Agrifood Research Finland - Agricultural Engineering
• Estonian University of Life Sciences

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Energy and Agriculture in Estonia and Finland

ENPOS
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Contents

1 What is energy?

If we have energy then we are able to do work. Energy can be in various forms, it can be kinetic or potential or radiation energy or it can thermochemical energy which is released during burning. Burning can be directly utilised in heating or it can be converted to mechanical work e.g. in internal combustion engines.

Table 1.1: Energy units and conversion factors

	MJ	kWh	toe	kcal
MJ	1	0.27778	0.00002388	238.89
kWh	3.6	1	0.00008598	860
toe	41990	11630	1	10000000
kcal	0.004199	0.001163	0.0000001	1

Depending on the energy type it is sold and measured in different units. Small consumers buy oil in liters but crude oil is sold in barrels (oil barrel = 42 US gallons = 158.9873 litres). Firewood is sold in cubic meters (m^3), electricity is sold for small consumers in kWh, for large consumers in MWh and the electricity consumption in nation scale is shown in TWh. For energy calculations we must convert the different energy amounts into the same unit for calculation and comparison. The basic energy unit is Joule (J, 1 J = 1 N·m = 1 $\frac{kg \cdot m^2}{s^2}$). Some of the energy units and their conversion factors are shown in table 1.1. The prefixes associated with SI units are shown in table 1.2.

Name	deca-	hecto-	kilo-	mega-	giga-	tera-	peta-	exa-	zetta-	yotta
Symbol	da	h	k	M	G	T	P	E	Z	Y
Factor	10^1	10^2	10^3	10^6	10^9	10^{12}	10^{15}	10^{18}	10^{21}	10^{24}
Name	deci-	centi-	milli-	micro-	nano-	pico-	femto-	atto-	zepto-	yocto-
Symbol	d	c	m	µ	n	p	f	a	z	y
Factor	10^{-1}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}	10^{-21}	10^{-24}

Table 1.2: Standard prefixes for SI units

2 Energy contents of materials

Energy contents of materials are determined with bomb calorimeters (Fig. 2.1). A small portion of the material is put in the calorimeter and this amount is burned and the energy released during burning is recorded. The more precise working principle of bomb calorimeter can be found for instance at www.chem.hope.edu/~polik/Chem/bombcalorimetry.htm . Bomb calorimeter gives the maximum energy (heating value), which can be released from a material. Altogether three different heating values can be determined for material

- Higher heating value (HHV, gross caloric value, upper heating value). When hydrocarbon fuel is burned the flue gases include vapour. The energy needed for vaporisation is included in the higher heat value.
- Lower heating value (LHV, net calorific value). The heat of flue gas vapour is not included in the upper heating value.
- Gross heating value. Many materials like biomass contain besides dry matter also water. This has to be taken into account when the heating value of wet material is defined. Only part of the fuel mass is burnable (dry matter) the other part is water, which vaporises during the dry matter burning. Gross heating value is calculated from the fuel lower heating value.

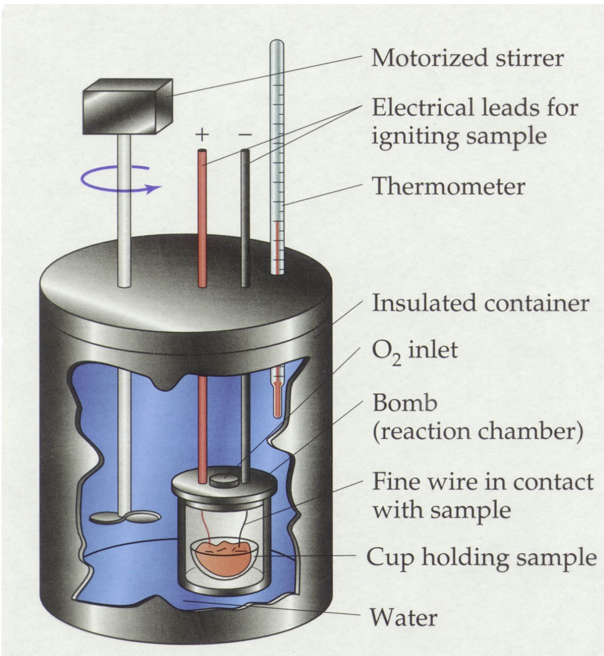

Figure 2.1: Bomb calorimetry (HTTP://chemistry.umeche.maine.edu/~amar/fall2007/bomb.html)

Gross heating value of wet material can be defined with equation 2.1. The first part of the equation determines what is the dry matter content of the wet material and the latter part defines the energy needed to vaporize the moisture of the material. Lower heating value is mostly used in burning calculations because the flue gases are usually not cooled down to the environmental temperature.

$$H_g = H_{LHV} \cdot (1 - w) - 2.443 \cdot w \tag{2.1}$$

H_g	=	gross heating value [MJ/kg]
H_{LHV}	=	lower heating value of material [MJ/kg]
w	=	moisture content of material

Lower heating values of biomass can be found at table 2.1. The values are approximate values, crop type and wood type have some influence on the heating value.

Table 2.1: Lower heating values of bio materials [Alakangas 2000]

Material	Lower heating value H_{LHV} MJ/kg
Crops	20
Crop straw, reed canary grass	17 - 18
Rape and flax straw	18 - 19
Rape seed	26
Wood	18 - 20
Peat	20 - 21
Light heating oil	42 - 43

Example. Wheat moisture content is 15%. What is the gross heating value of the material?

The gross heating value is according to equation 2.1 $H_g = 20 \cdot (1 - 0.15) - 2.443 \cdot 0.15 = 16.6$ MJ/kg.

3 Work and power

In physics work is determined by multiplying force with distance. If it is a rotating work, then torque is multiplied with angle, equations 3.1 and 3.2. Power expresses how fast the work is done and power is calculated by dividing the work with the time used for the work, 3.3 and 3.4.

$$W = F \cdot s \tag{3.1}$$

$$W = M \cdot \alpha \tag{3.2}$$

$$P = \frac{W}{t} \tag{3.3}$$

$$P = \frac{F \cdot s}{t} = F \cdot v \tag{3.4}$$

$$\begin{aligned} \mathrm{W} &= \text{work} \\ \mathrm{F} &= \text{force} \\ \mathrm{s} &= \text{distance} \\ \mathrm{M} &= \text{torque} \\ \alpha &= \text{angle} \\ \mathrm{t} &= \text{time} \\ \mathrm{P} &= \text{power} \\ \mathrm{v} &= \text{speed} \end{aligned}$$

In electricity power is the product of current and voltage. When we have direct current power is calculated with equation 3.5. In alternating current the phase between current and voltage must be taken into account. The phase value is given in the type plate of the machine as cosϕ value. One phase power can be calculated with equation 3.6 . Three phase power can be calculated by summing each phase or if the load is symmetric, then power can be calculated with equation 3.7.

$$P = UI \tag{3.5}$$

$$\begin{aligned} \mathrm{U} &= \text{voltage} \\ \mathrm{I} &= \text{current} \end{aligned}$$

$$P = UIcos\phi \tag{3.6}$$

$$\phi = \text{phase shifty between voltage and current}$$

$$P = \sqrt{3}U_p I_p cos\phi \tag{3.7}$$

$$\begin{aligned} U_p &= \text{main voltage (nominal 400 V)} \\ I_p &= \text{main current} \end{aligned}$$

The equations above only show the power taken from the power grid. Single electrical devices have their own efficiencies and the actual produced power is always lower than the consumed electricity.

Example. A harrow needs 10 kN pulling force and the driving speed is 11 km/h. What is the work done in tillage when the working width is 5m?

P=Fv = 10 kN$\cdot \frac{11}{3,6} \frac{m}{s}$= 30,6 kW. Tractor engine power is clearly higher than this, because part of the engine power is needed to propel the tractor. Work rate during tillage is q=bv=5m$\cdot \cdot \frac{11}{3,6} \frac{m}{s} = 15,3 \frac{m^2}{s}$= 5,5 ha/h. To harrow one hectare 0,18 h time is needed and the work done is 30,6 kW·0,18h=5,6 kWh. One kWh = 1000 W·3600s = 3,6 MJ and when the unit is changed to the basic unit the corresponding work is 20,2 MJ/ha.

Note that the load of the work done determines the power needed and the engine or the motor produces this. The engine or the motor does not use the nominal power shown in the specifications unless the load is high enough.

Example. The type plate of an electric motor of a pump shows the nominal power of 11 kW and $cos\phi$ of 0,85. What is the power taken from the grid?

This example cannot be calculated without knowing the motor load. This can be measured for instance by measuring the current taken from the grid and the voltage . Measurement shows that the motor takes 6 A current from the grid. Now we can calculate the electric power, P=$\sqrt{3} \cdot 400V \cdot 6A \cdot 0,85$= 3,5 kW.

Previously we have handled mechanical and electrical work and power. In agriculture also air or liquid flow is needed. Air is used to dry bio materials and to take care of good micro climate in cattle houses. In hydraulics oil flow and pressure are used for work and in water supply water is pumped to the consumption. Power in air or liquid flow is calculated with equation 3.8.

$$P = q_v p \tag{3.8}$$

q_v = volume flow
p = pressure

Example. Grain dryer furnace has an air flow of 18 000 $\frac{m^3}{h}$. Dryer and grain makes a counter pressure of 400 Pa. What is the power in the flow?

P=$18000 \frac{m^3}{3600s} \cdot 400Pa$= 2000 W.

With combustion engines fuel consumption can be used for work calculations. When fuel consumption is known, the fuel heat value and the engine efficiency can be used for the calculations, equation 3.9.

$$W = H_g \cdot q_{pa} \cdot \rho \cdot \eta_{mo} \tag{3.9}$$

W = work
η_{mo} = engine efficiency
ρ = density
q_{pa} = fuel consumption

Engine efficiency can be calculated from the specific fuel consumption, equation 3.10. Specific fuel consumption depends on engine load and characteristics. When the engine is loaded powerfully, diesel engine specific consumption is 220 - 270 g/kWh. With light load the consumption is 300 - 400 g/kWh.

$$\eta_{mo} = \frac{1}{H_g \cdot q_{om}} \tag{3.10}$$

Combining equations 3.9 and 3.10 gives equation 3.11.

$$W = \frac{q_{pa} \cdot \rho}{q_{om}} \tag{3.11}$$

Example. During ploughing fuel consumption is 18 l/ha and because the work is hard the engine is loaded well and the specific consumption is 250 g/kWh. Fuel density is 0,83 kg/l. What is the work done?

During ploughing: W= 18 l/ha·0,83kg/250g/kWh = 59,8 kWh/ha = 215,3 MJ/ha.

4 Energy consumption in agriculture

World energy consumption is increasing and the increase is based on fossil energy availability. At the same time fossil energy resources are diminishing and the wide use of fossil energy has already caused global warming. This has led to discussions and usage of bio energy and renewable energy. At the moment the share of renewable energy is about 13% of the whole energy supply [IEA 2008]. Renewable and bio energy usage and research has been favored in many countries. For instance EU has decided to stop the climate warming to two degrees and the share of renewable energy in 2020 should be 20%. The fossil energy resources are decreasing, which means that their prices will be increasing and in the future there will be shortage of fossil energy. This means changes also in agricultural production. Although agriculture uses a lot of fossil energy, it is at the moment in plant production energy positive, we get more energy out of production in the form of food and feed than we use in the production. In animal production the farm is in most cases energy negative, more energy is used in the production than we get from the product. In the future the farms must be more and more self-sufficient in energy usage. This means energy savings, better nutrient recycling and at the end the farm could be energy positive in the sense that besides food, feed and fibre it also produces energy. In energy savings new methods which consume less energy than old methods must be introduced. For instance direct drilling consumes less energy than conventional drilling and unheated cattle houses consume less energy than heated houses.

Figure 4.1 presents the usage of fields, crop yield and the usage of fertilizers during the years 1961 – 2008 [Faostat 2010]. During this period the world population has more than doubled, crop field area has remained almost the same, fertilizer use has become six-fold, and crop yield has doubled. From the picture the conclusion can be drawn, that the population of the world has been nourished with the increasing usage of fertilizers. Some 94% of the energy consumed by the fertilizer industry is used for ammonia synthesis and fertilizer production consumes 1.2% of the world's total energy on annual basis. Natural gas is the primary hydrocarbon feedstock used in ammonia synthesis from which almost all nitrogen fertilizers are derived.

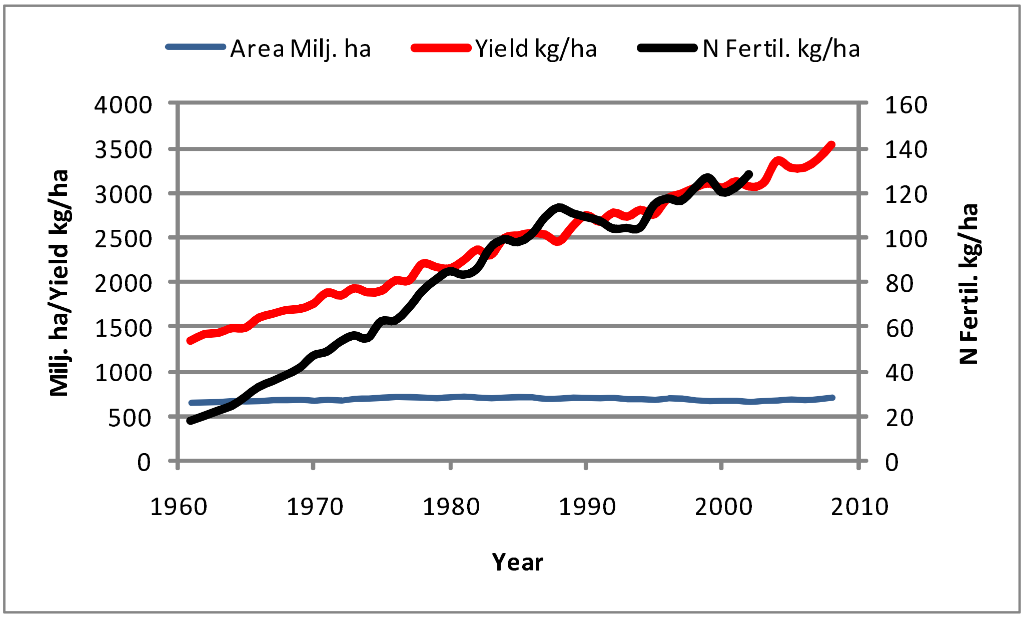

Figure 4.1: World field area, yield and nitrogen fertilizer use

Direct energy use in agriculture is small when compared to other sections. In OECD countries agriculture's share of the national energy consumption in 2002 - 2004 was only 2%. In OECD countries, on-farm energy consumption increased by 3% compared to 19% increase for all sectors (1990-92 to 2002-04), but nearly half of the member countries reduced their agricultural energy consumption. Diesel and gasoline form the main part of the energy consumption. Renewable energy use has increased notably from 1990-1992 to 2002-2004 in Austria, Denmark, and Finland. The share of electricity has also increased in many countries [OECD 2008]. Besides direct energy agriculture consumes also indirect energy in the form of chemicals, feed, machines, and buildings. This part is in many cases larger than the direct energy consumption.

Because of the small share of agriculture on total energy consumption savings in agricultural energy consumption do not have much influence on the national energy consumption. There are however large emissions from agriculture for instance nutrient leaching into watershed, nitrogen dioxide emissions to the atmosphere because of the wide use of nitrogen fertilisers, and methane emissions from ruminants.

In 1950 world population was 2.6 billion inhabitants, in 2000 it was 6.1 billion and in 2010 6.9 billion. The forecast for year 205 is 9.5 billion people [UN World population]. This has a great effect also on agriculture, food production must be increased at least at the same speed as the population grows. Modern agriculture is based on cheap fossil energy and to be able to produce more food with less available energy is a challenge in agriculture in future.

4.1 Energy flows in agriculture

Figure 4.2 shows an estimation of the energy flows of the Finnish agriculture in 2001. The direct energy input (electric grid power, electric power from biogas, heavy fuel oil, diesel and light fuel oil, gasoline, natural gas, fire wood, peat, earth heat, district heat) and indirect energy input (mixed feed production, fertiliser, herbicides and pesticides, farm machinery) was compiled by Nyholm et al[Nyholm et al. 2005] and partly updated. The energy output was calculated from the production data [Statistics Finland 2004] using mass to energy conversion factors after Rydberg and Haden[Rydberg and Haden 2006] and Lampinen and Jokinen [Lampinen and Jokinen 2006]. The overall crop production output of 1607 GJ/farm is much higher than the energy input, because the sun energy conversion by photosynthesis usually is not taken into consideration in predominating energy analysis methods. The crop production output splits into 520 GJ/farm for human nutrition crops and feed for animals. Energy crops are not allocated separately.

Because farms usually specialise into crop- or animal production it is important to keep in mind that these results are the average of all farms and not typical for crop production or animal production farms. However, the figures stress the importance of developing energy positive farms and may serve as reference for the case farms setting up energy saving priorities.

4.2 Energy use in plant production

Typical energy consumption figures are given in table 4.1. These values vary according to soil type and moisture content, machine driving speed and settings, vegetation and machine type. Thus the values are only typical values for these work and variation can be large. The size of a tractor or an implement has a small effect on energy consumption. During cultivation for example, we must do certain work with which the soil is broken and this causes the basic energy need. When machines are chosen in a correct way the influence of machines is small.

Usually the fuel and energy consumptions are added and converted into basic energy units with the help of the heat contents of the fuels. In table 4.2 the energy contents of different fuels have been given. For bio fuels the heat value depends on moisture content (equation 2.1).

Fuel consumptions are summed together and then they are changed with the fuel heat value to basic SI units, equation 4.1.

$$E = H_a \cdot q_{pa} \cdot \rho \tag{4.1}$$

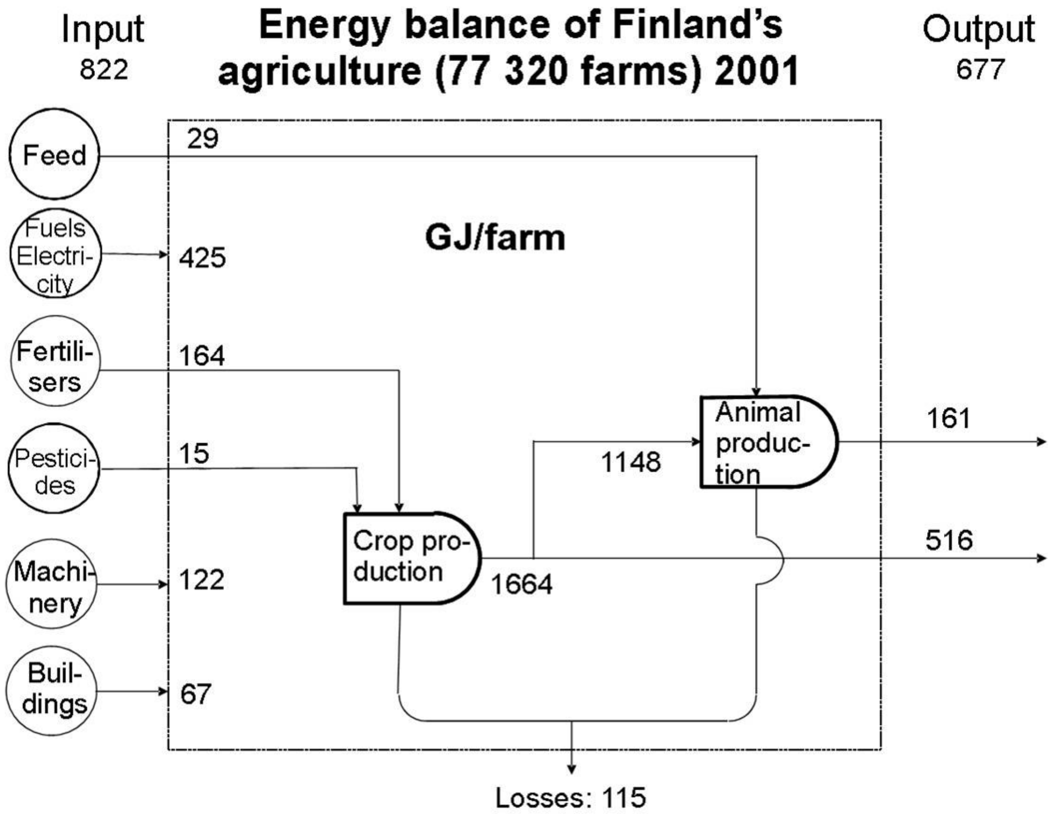

Figure 4.2: Energy flows in Finnish agricultural production

E	=	energy
q_{pa}	=	fuel consumption
ρ	=	fuel density
H_a	=	lower heat value

Example. During ploughing 25,1 l/ha fuel is needed in average. What is the corresponding energy amount? When the density of the fuel is 0,83 kg/dm^3 and lower heat value is 42,8 MJ/kg, 25,1 l/ha corresponds to 892 MJ /ha. This can be changed into a unit of kWh, in which case 248 kWh is obtained.

The energy needs are calculated over the production season including all work that has been done on the field is included. Also the transports and grain drying are taken into consideration.

Example. The cultivation season includes ploughing (25 l/ha), harrowing three times (16 l/ha), drilling (4 l/ha), spraying (2 l/ha) and harvest (15 l/ha). Together 62 l/ha energy is needed for the field works.

In grain drying 120 g light burning oil is needed per evaporated water kilogram. This corresponds to 5,2 MJ or 1,4 kWh of an amount of energy. The moisture of the grain to be harvested vary every year and the evaporated water amount and the necessary amount of energy change accordingly to this, equation 4.2.

$$M_{vp} = M_s \frac{w_a - w_l}{1 - w_a} \tag{4.2}$$

M_{vp}	=	evaporated water amount
M_s	=	yield at storage moisture content
w_a	=	harvesting moisture content
w_l	=	storage moisture content

Table 4.1: Typical energy consumption figures in plant production [Mikkola and Ahokas 2009]

Work	Fuel consumption l/ha
Ploughing	25,1
Stubble cultivation, tine harrow	10,0
Stubble cultivation, disc harrow	7,2
Levelling of field	4,5
Secondary tillage	5,4
Drilling, combined seeding and fertilizing	3,7
Direct drilling	7,6
Fertiliser spreading	2,9
Spraying	1,8
Combine harvesting	15,1
Mowing	6,0
Grain drying	120,0 g oil/evaporated kg water
Baling	0,5 l/bale
Road transport	0,06 l/ton·km
Nitrogen fertiliser manufacturing	49,2 MJ/kg
Phosphorus fertiliser manufacturing(P_2O_5)	15,5 MK/kg
Potassium fertiliser manufacturing(K_2O)	9,7 MJ/kg
Pesticide manufacturing	273,6 MJ/kg
Lime	1,3 MJ/kg

Example. The annual grain yield of a farm is 350t (13% wb). The average threshing moisture content is 22% and grain is dried to 13% moisture content. How much wood chips must be reserved for the drying?

The amount of water to be removed will be first calculated. For the removal of every water kilo 5,2 MJ of energy is needed, in other words altogether 210 GJ or 58350 kWh of energy is needed. If wood chip has 25% of moisture content, the amount of energy in one chip kilogram is 13,6 MJ/kg according to the equation 2.1. If the volume weight of the chip is 200 kg/m^3, 77 m^3 will be enough. When furnace efficiency is estimated to be 80 %, the real wood chip need is 96 m^3.

4.3 Energy consumption in animal production

During the resent years the number of dairy herds is decreased and at the same time, average herd size is increased both in Estonia and Finland. In Estonia more than 130 dairy farms were built or reconstructed from 2005, thus by the end of 2009, over 40% of cows were on new or reconstructed farms (Figure **??**).

Energy consumption of cattle farms is depending on a housing system, ambient temperature (season), technical condition of a farm and efficiency [BAT 2007]. Electric energy is one of the most expensive types of energy, yet it is most easy to be used in technological processes. Table 4.3 shows approximate energy consumption in a tie stall and loose housing barns in Estonia with 300 animal places. In cattle barns there is not necessary need to heat barns as animals themselves generate body heat which is sufficient to maintain welfare temperature within installation. Heat energy is however consumed for preparing warm water for washing and for heating of service and resting rooms. At some farms heat energy is recovered from milk in its cooling process and used to heat water for milking parlour.

Energy consumption depends on production type and mechanisation level. This causes quite varying consumption figures. In table 4.4 is shown consumption figures gathered by Hörndahl [Hörndahl 2008]. For instance for milking cows the energy consumption in ventilation can be zero in natural ventilation but in forced ventilation electricity is needed to run the blowers. The production may need also other

Table 4.2: Lower heating values and CO_2 emissions as fired of fuels [Statistics Finland 2010]

Fuel	CO_2emission g/MJ	Heat value MJ/kg	Density kg/dm^3
Liquid gas	65,0	46,2	
Petrol	72,9	43,0	0,75
Diesel oil	73,6	42,8	0,82 - 0,84
Light burning oil	74,1	42,7	0,82 - 0,84
Heavy burning oil	78,8	41,1	0,9 - 1,0
Natural gas	55,04 kg/m^3	36,0 MJ/m^3	
Milled peat	105,9	10,1	
Wood normal use moisture content	109,6	7,5 - 14,0	0,4 - 0,6
Reed canary grass	100,0	14,6	
Grain and straw	109,6	13,5	
Biogas	56,1 kg/m^3	20,0 MJ/m^3	

Table 4.3: Approximate annual electric energy consumption in dairy farms per animal place in Estonia

Production process	Tie stall housing, kWh/animal place	Cold barn and loose housing, kWh/animal place
Preparation of feeds and feeding	17 ... 23	1.0...3.0
Milking	110.0...135.0	190.0...210.0
Heating the water and rooms	130.0...180.0	50.0...80.0
Lighting	70.0...90.0	19.0...22.0
Manure removal	105.0...135.0	7.0...11.0
Total	432.0...563.0	267.0...326.0

electrical equipment like electric heaters, computers and automation control equipments. In milking consumption of washing the milking machinery and milk cooling are also included. The feeding systems can be very different and also the consumption of feeding equipment varies.

The total energy consumption in animal production consists of the direct energy consumption mentioned above and usually the feeding material energy consumption during production. The energy needed for grain or grass production is calculated from the plant production figures, section 4.2. In table 4.5 are shown specific energy consumption figures in animal production.

The main fuels used in cattle farms are diesel fuel, light fuel oil, natural gas and wood. Diesel fuel is used for operating vehicles in transporting and distributing feeds, removing manure etc. Light fuel oil and wood are used for producing heat energy in heating systems and for getting warm water. Diesel fuel is more expensive than electric energy, yet using it in vehicles is inevitable. As for heating, the cheapest fuel is firewood which is technologically quite inconvenient to use. The use of chips or pellets can be more effective. The fuel consumption structure is significantly affected by housing technology and varies in different barns. Table 4.6 presents approximate annual diesel fuel consumption per animal place in a barn with 300 animal places.

Energy efficiency within Estonian pig farming was investigated in 2004 [Energy Efficiency] in cooperation with Danish researchers. To collect information on electricity consumption, three pilot farms were analysed with regard to the use of energy consumption on each farm. Results from the three farms are presented in Table 4.7. These Estonian levels of consumption per pig and sow were compared with corresponding figures for Denmark. Comparison between Estonian and Danish figures showed a higher

Table 4.4: Animal production energy consumption figures [Hörndahl 2008, Mikkola and Ahokas 2010].

	Milk kWh/cow/year	Pork kWh/pig place/year	Egg kWh/hen place/year
Illumination	2 - 230	0,3 - 6,3	0,001 - 2,4
Milking	220 - 680		
Feeding	18 - 640	1 - 89	0,003 - 0,13
Manure removal	0,2 - 100	0,1 - 8	0,01 - 1,2
Ventilation	1 - 160	18 - 32	1,3 - 2,2
Other	1 - 145	1,9 - 164	0,03 - 0,30

Table 4.5: Specific energy consumption in animal production [Hörndahl 2008]

Production	Specific energy consumption
Milk, kWh/l milk	0,3 - 0,9
Pork, kWh/kg meat	4,4 - 8,1
Egg, Wh/kg egg	150 - 250
Broiler, Wh/broiler	910

consumption per pig in Estonia than in Denmark:

- For sows the consumption was 36 percent higher
- For pigs the consumption was 64 percent higher.

The calculation of national level energy consumption within pig production was also investigated. Total consumption in piggeries was 30 323 MWh in a year. Sows (46 500 animals) consumed 24 134 MWh and finishing pigs (290 000 animals) consumed 6 189 MWh.

Energy consumption in animal production has not been studied much and the energy efficiencies of different production systems have not been analysed widely. This subject needs more study to find out energy efficient practises.

4.4 Energy use in buildings

Energy consumption of buildings can be examined by defining the energy flows coming and leaving the building. When animal production is in question, the feed that has been taken to the animal production can also be then changed to energy flow to the system according to its heat contents. For energy comparison the consumption per produced unit is used. This takes into account the production differences and allows us better compare different kind of productions. For example production can be calculated per animal or per produced product (milk, meat). An additional problem is that for example milk cow also produces calves and meat. Then the used energy must be allocated between different productions.

When there is a temperature difference between a building and outdoor air, heat will flow from the warmer side to the colder side. In the northern circumstances it is mostly a question of heat flowing out of the building in which case heating is needed to replace heat defeats. In hot summer the situation is vice versa, the heat flows from outside to the building causing the building to become hot. Heat can move in three different ways. By conduction the heat moves through the structures, by convection the heat moves from one place to another. This can take place freely, in which case, the temperature differences cause density differences, which causes the heat flow. Conduction can also be forced, for example with the help of a pump or blower liquid and air and with these also heat is transferred. The heat can also move as radiation, for example as an infrared radiation from the radiation heaters, sun

Table 4.6: Approximate annual diesel fuel consumption for technological processes per animal place (kWh/year/animal place)

Technological process	kWh/year/animal place	kWh/year/animal place
Feed distribution	4.0...8.0	48.0...96.0
Manure removal	6.0...10.0	72.0...120.0
Total	10.0...18.0	120.0...216.0

Table 4.7: Energy consumption per pig in Estonia

Consumption (kWh/pig/year) for	1 sow with piglets and weaners	1 growing / finishing pig
Feeding + preparing feed	29	3.78
Ventilation	136	7.25
Heating	316	6.83
Lightning	15	1.01
Water pumping	8	0.78
Removing manure	15	1.69
Total consumption	518	18.03

or fireplace. The heat losses of production buildings consist of the heat losses through the structures and heat losses through the ventilation.

4.4.1 Heat conduction

Heat power in conduction is obtained from equation 4.3 , figure 4.3. The magnitude of heat power depends on thermal conductivities of the structural materials, on size of the building and on temperature difference. The better the insulation materials are, the smaller the heat power requirement is. Low ambient temperatures cause a large temperature difference between the building and the outside and the heat power need is high. In a large building there is a lot of area which conducts heat. The need of the maximum power of the heating can also be estimated on the basis of the volume of the building. In new dwelling house 25 - 30 W/m^3 is needed and in old ones 35 - 50 W/m^3.

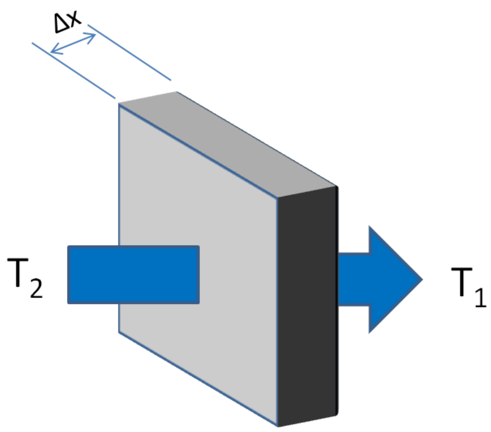

Figure 4.3: Heat flow through a wall

$$P = \frac{\triangle Q}{\triangle t} = \lambda A \frac{\triangle T}{\triangle x} \tag{4.3}$$

Q	=	heat current
t	=	time
λ	=	thermal conductivity
A	=	cross section area
$\triangle T$	=	temperature difference
$\triangle x$	=	wall thickness

Isolation material densities and thermal conductivities are shown in table 4.8

Material	Density kg/m^3	Thermal conductivity $\frac{W}{m \cdot K}$
Air	1,2	0,024
Leca-gravel	270 - 400	0,08 - 0,10
Glass wool	50 - 70	0,045 - 0,050
Rock wool	20 - 250	0,040 - 0,070
Saw dust	120 - 200	0,08 - 0,12
Brick	1600 - 1800	0,4 - 0,9
Wood	500	0,14
Concrete	2300	1,7
Grain	600 - 800	0,13 - 0,14 (14% moisture)

Table 4.8: Material densities and thermal conductivities [Ympäristöseloste]

Example. Thermal conductivity of wall is 0,35 $\frac{W}{m^2K}$.If wall thickness is 200 mm and wall area is 30 m^2, what is the conductive heat flow through the wall? Inside temperature is 22 °C and outside temperature is - 20 °C.
Temperatures difference ΔT= 22 °C - (- 20 °C) = 42 °C, when P=0,35$\frac{W}{m \cdot K} \cdot 30m^2 \frac{42\text{K}}{0{,}2m}$=2,2 kW

Material moisture content and temperature has an effect on thermal conductivities. In reality the coefficients are not absolutely constant but they vary with varying conditions. The wall structures are not made from only one material but they consist of several materials. In theses cases conduction is calculated with overall heat transfer coefficient (U-coefficient). The U-coefficient for each wall layer is calculated with equation 4.4

$$U = \frac{\lambda}{L} \tag{4.4}$$

U	=	material heat transfer coefficient
λ	=	thermal conductivity
L	=	material thickness

Wall heat conductivity depends on its structure. Isolation material and its thickness effect most on thermal conductivity. Heat can flow also through wall with convection, if the wall does not have wind shield characteristics. Also moisture can destroy heat insulation material if it penetrates in the material and moisture condensates. Total U-coefficient of the wall can be calculated from the layer U-coefficients, equation 4.5.

$$\frac{1}{U} = \frac{1}{U_1} + \frac{1}{U_2} + ... + \frac{1}{U_n} \tag{4.5}$$

Example. The wall consist of 150 mm thick glass wool (λ= 0,05 $\frac{W}{mK}$) and 22 mm thick wood board (λ= 0,14 $\frac{W}{mK}$) on both sides. If the wall area is 50 m^{2}what is the heat flow through the wall when temperature difference is 30 K?

U-coefficients for the layers are: outside board U_1 = 0,14W/mK/0,022m = 6,36 W/m²K, insulation U_2=0,05/0,15 = 0,33 W/m²K and inside board $U_3 = U_1$. The wall U-coefficient is: 1/U = 1/6,36+1/0,33+1/6,36 = 3,34 $\Longrightarrow$U = 0,30 W/m²K. Heat power flowing through the wall is: P = 0,30 W/m²K·50 m²·30 K = 0,45 kW.

Walls have normally windows and doors. The U-coefficients of these are different from the wall values. Typically they U-coefficients of 2 - 3 $\frac{W}{m^2K}$. Normally their heat losses are calculated separately or mean U-value is calculated for the walls.

The temperature in building forms layers so that at the ceiling the temperature is warmer than at the floor. The temperature difference is so higher at the upper part of the building. Also the insulation material recommendations take this into account and the isolation demands are higher.

At floor level the temperature under the floor is warmer during cold weather than the outside temperature. For this reason heat losses through floors are lower than other parts of the building. The heat losses at the floor are highest at the outside perimeter. The heat flows there from the floor to the soil and from the soil to air. Floor insulation material is for this reason put under the floor mainly near the outside walls. Heat losses through the floor is difficult to calculate precisely because the soil temperature under the floor should be known. The recommended way for the calculations can be found for instance from National Building Codes of Finland [National Building Codes]. For a course calculations the heat loss is 6 W/m^{2}for a 300 m^{2}floor area and 13 W/m^{2}for 50 m^{2}area.

4.4.2 Heat loss in ventilation

Production buildings must have an adequate ventilation to keep the animal welfare in good order. If the production buildings are heated, in these cases the ventilation produces heat losses, warm air is taken out and cold air is streaming in. The heat loss of ventilation can be calculated with equation 4.6.

$$P = c_i \cdot q_v \cdot \rho_i \Delta T \tag{4.6}$$

P	=	heat loss in ventilation
c_i	=	specific heat capacity of air, 1,0 $\frac{kJ}{kg \cdot K}$
q_v	=	ventilation air flow
ρ_i	=	air density
ΔT	=	temperature difference

Ventilation rate demand changes with ambient temperature change. In warm weather heat removal is the main demand. In cold weather it can be either CO_2 or moisture removal. Figure 4.4 shows an example of ventilation rate dependence on animal weight. During the summer time the heat removal is the main ventilation demand and it is clearly higher than the other demands. For this reason it is called the maximum ventilation. During winter we have the minimum ventilation. Besides animals human working conditions or the building condensation risk can determine the ventilation rate.

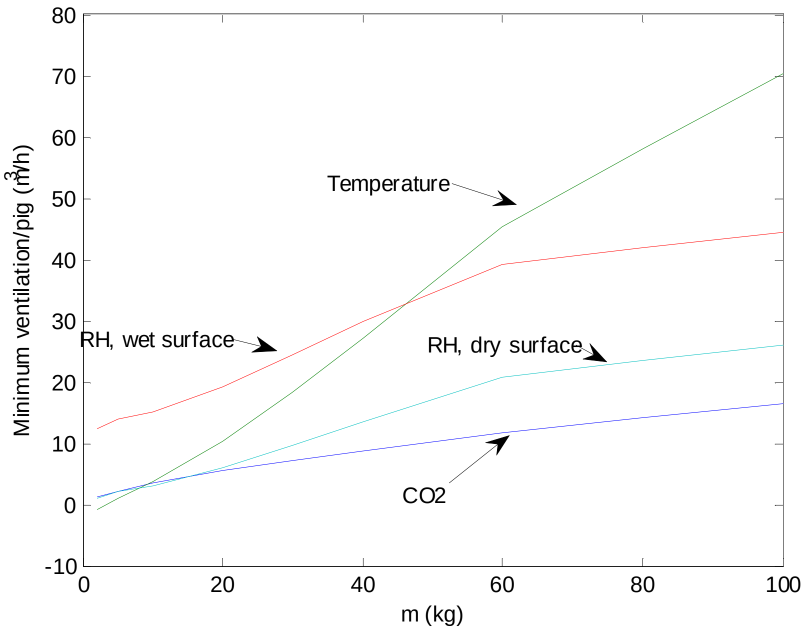

Figure 4.4: Dependence of ventilation rate of pig weight in a piggery at 0°C and 100% relative humidity outside

Example. One milking cow needs in minimum ventilation rate of 55 m^3/h. If the inside temperature is 12 °C and outside temperature is -20 °C, how much energy is needed to warm up the ventilation flow for one cow?

Air density is about 1,2 kg/m^3. P=1,0 $\frac{kJ}{kg \cdot K} \cdot \frac{55m^3}{3600s} \cdot 1,2\frac{kg}{m^3}(12+20)K$ = 0,6 kW. One cow produces about this amount of sensible heat, so the cow's own heat production is enough to warm her ventilation rate need. Also the building has a heat loss, which means that to keep the temperature we need extra heating.

5 Energy analysing methods

5.1 System analysis method

Energy usage and specific energy consumption can be analysed using system analysis methods. In system analysis detailed energy conversation phenomena is not necessary to know but only the energy flows through the borders defined by the analyzer are examined. Figure 5.1 gives an example of plant production system with boundaries and the flows through the boundaries. In energy analysis the inputs and outputs are used to determine the efficiency of the system.

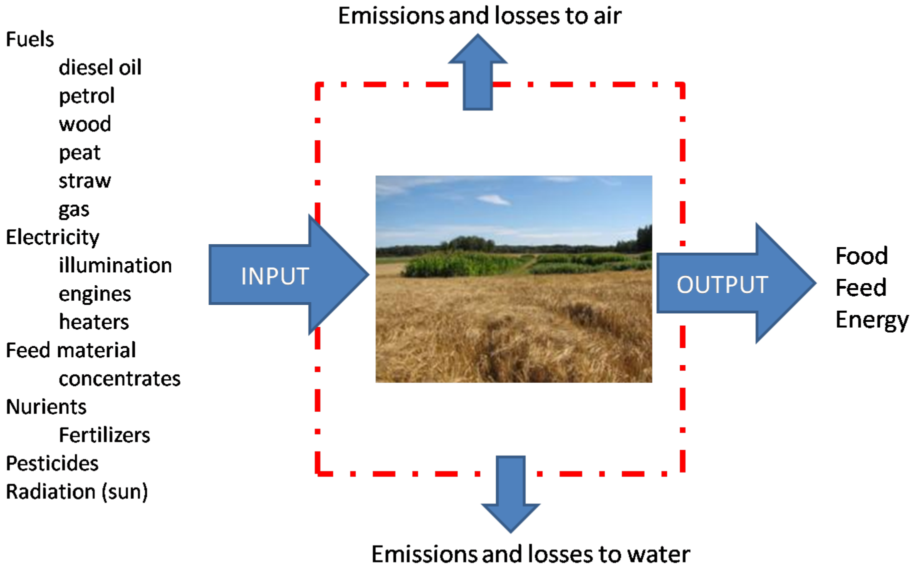

Figure 5.1: Example of plant production system and energy flows

In system analysis the boundaries position plays an important role. They dictate what is icluded in the analyses. For instance in crop production the farmer uses his own seeds, depending on the boundary the output of the farm can be the total yield or the seeds are subtracted from the yield.

Example. The farm uses annually (input) 21 GJ/ha and the yield is 53 GJ/ha (output). The farm system produces 32 GJ/ha energy more that it uses in the production.

5.2 Balances

In energy and other analysis mass and energy balances are vital part of the work. They reveal if there are shortcomings in the production. Energy and mass conservation laws state that there should always be a balance between the input and output. Output can never be over one compared to input and when all the losses have been carefully included in the analysis the output and input should be about equal. Figures over one or big differences between them indicate errors in the analysis or the fact that some important energy item is missing from the analysis.

Energy balance

In energy balance the material flow into the system (farm) and out of the system are analyzed. If all the inputs and outputs are calculated, the energy balance should be one. In practice it is in many cases hard to measure all the material flow but at least the most significant flows should be identified. In plant production the energy balance is often calculated without the energy of sun radiation and when this is not included the energy efficiency is greater than one.

Nutrient balance

Nutrient balance is a part of mass balance analysis. In nutrient analysis the amount of different nutrients used in the production and the amount of nutrients harvested with the yield are compared. Because of losses the output is less than the input. The soil however accumulates nutrients resulting sometimes in greater output than input when the nutrient stores in soil are utilized..

5.3 Energy ratio

In agricultural production the energy efficiency of the production is defined with energy ratio (Equation 5.1).

$$N_e = \frac{E_o}{E_i} \tag{5.1}$$

N_e = energy ratio
E_o = energy output of the production (caloric heating value)
E_i = energy input of the production

Example. The farm uses annually (input) 21 GJ/ha and the yield is 53 GJ/ha (output). The energy ratio is $N_e = \frac{53}{21} = 2.5$

Energy ratios can be calculated in different ways. It is normal that in agricultural production all the direct energy consumptions are included and also fertilizers as indirect energy consumption is included. Machinery and building indirect energy is many times neglected. The analyzer should always explain what has been included in the analysis.

5.4 Net Energy Gain

Net energy gain N_g is the difference between the energy output and input (Equation 5.2).

$$N_g = E_o - E_i \tag{5.2}$$

Example. The farm uses annually (input) 21 GJ/ha and the yield is 53 GJ/ha (output). The net energy gain is $N_g = 53 - 21 = 32\text{GJ/ha}$.

Figure 5.2 shows energy ratios and net energy gains calculated for Finnish plant production. For crops energy ratios are between 2 and 5. Lay and reed canary grass have higher energy ratios from 5 to 18. This is due to the fact that the harvested biomass of these plants is high. The straw of crops is not utilized in most cases and the total biomass is lower. Energy ratio maxima are achieved on low fertilizer level. Long term low usage of fertilisers can lead to soil nutrient decrease. In order to keep the soil in good growing conditions fertiliser application should at least cover both nutrient losses of leakage and nutrients within the products leaving the farm gate .

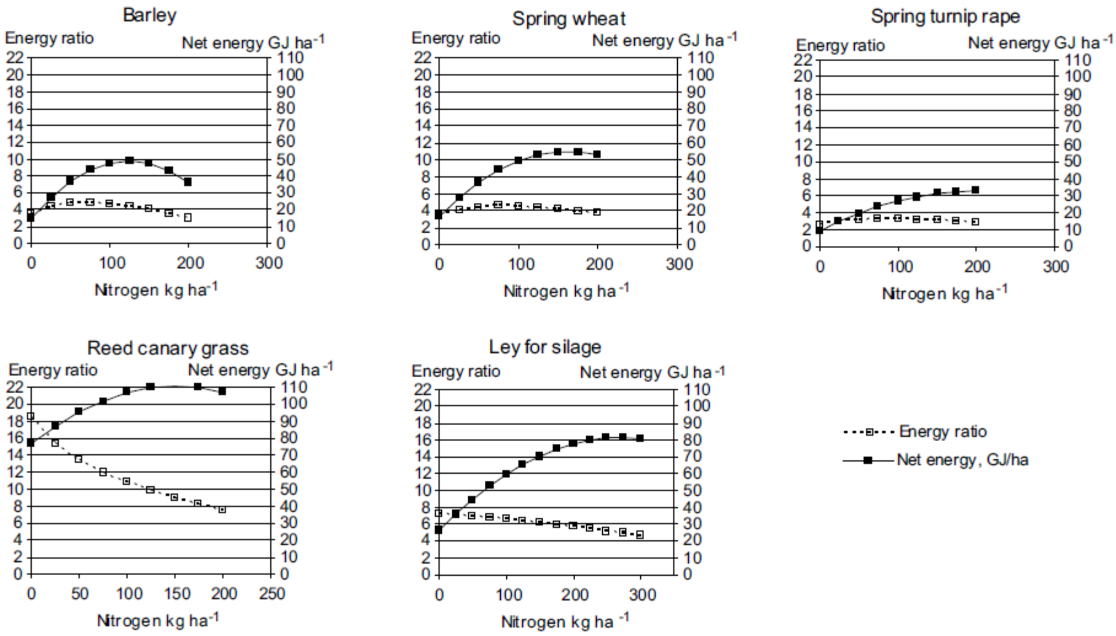

Figure 5.2: Energy ratios and net energy gain in Finnish agricultural production ([Mikkola and Ahokas 2009])

5.5 Specific energy ratio

Specific energy ratio is used when we want to analyse the efficiency of the production (Equation 5.3). For instance we want to know how much energy we use in producing one kilogram of wheat or milk.

$$N_s = \frac{E_i}{y} \tag{5.3}$$

N_s = specific energy ratio
E_i = energy input of production
y = yield

Example. The farm uses annually (input) 21 GJ/ha and the yield is 3500 kg. The specific energy ratio is $N_s = \frac{21GJ}{3500kg} = 6MJ/kg$

5.6 Energy Return on Investment (EROI)

The term EROI is similar to the economic concept of financial Return on Investment but uses energy as currency. The basic EROI is calculated with equation 5.4.

$$EROI = \frac{E_o - E_i}{E_i} \tag{5.4}$$

$EROI$ = energy return on investment
E_o = energy output of the production
E_i = energy input of the production

For example the EROI of oil and gas in USA was 100:1 in the 1930's but declined to 10-17:1 by 2000 because an increasing amount of energy will be needed to explore difficult accessible fossil energy resources [Hagens and Mulder 2008]. "The more energy required to harvest, refine, and distribute energy to society, the less will be left for non-energy sectors"[Mulder and Hagens 2008].

The basic EROI is the same as the energy ratio (see equation 5.1). However, in contrast to the energy ratio the EROI embraces also indirect energy input and non-energy resources.

The most common form of EROI applies an appropriate methodology to assess the embodied energy costs of the non-energy inputs, which are termed the indirect energy and non-energy inputs. A detailed description of EROI calculation methods is described by Mulder and Hagens [Mulder and Hagens 2008]. On farm level the EROI can be calculated with equation 5.5.

$$EROI = \frac{(E_o + \sum O_x \cdot a_x) - (E_i + \sum I_y \cdot b_y)}{E_i + \sum I_y \cdot b_y} \tag{5.5}$$

$EROI$	=	energy return on investment
E_o	=	produced energy output
E_i	=	direct energy input
O_x	=	output
a_x	=	conversion factor of output O_x into energy
I_y	=	input
b_y	=	conversion factor of input$I_y$into energy

The term $\sum I_y \cdot b_y$is also called indirect energy input.

Example. In figure 4.2 the overall input of all fertilisers is 250 Gg/year and the mean conversion factor 36.5 GJ/Mg. The mixed feed production is 1375 Gg/year and the conversion factor 0.47 GJ/Mg. The agrochemicals input is 3.2 Gg/year and the mean conversion factor 360 GJ/Mg. Farm machinery input is 1195 Gg/year and the conversion factor 14 GJ/Mg. This mass inputs and conversion factors result in an overall indirect energy input of

$$\sum I_y \cdot b_y = \frac{250 \cdot 36.5 + 1375 \cdot 0.47 + 3.2 \cdot 360 + 1195 \cdot 14}{77320 \cdot Farms} \cdot 1000\, GJ = 357.6\; GJ/farm\; and\; year$$

The output is 4 Gg crops for human nutrition and the mean conversion factor 10 GJ/kg. Milk, meat, and eggs output is 2.8 Gg and the mean conversion factor 4.5 GJ/kg. The mass output than contains the following indirect energy or embedded energy:

$$\sum O_x \cdot a_x = \frac{4 \cdot 10 + 2.8 \cdot 4.5}{77320 \cdot Farms} \cdot 1\,000\,000\, GJ = 680\; GJ/farm\; and\; year$$

The direct energy input of all fuels in Finnish agriculture was E_i = 2 888 809 GJ corresponding to 425 GJ/farm. Than the EROI of Finnish agriculture was 2001:

$$EROI = \frac{680 - (425 + 357.6)}{425 + 357.6} = -0.13$$

6 Direct and indirect energy usage

The energy consumption can be split into two parts, direct and indirect energy. The allocation to these two energy parts is not always clear. Normally fuel and electricity are considered as direct energy use. Goods, including fuels, passing the system boundary need energy for production and transport. Also services require usually energy input. This part of energy is called indirect energy, sometimes also embodied or embedded energy. Some goods e.g. wooden construction materials could be used as fuel at the end of their lifetime. The caloric part of the good is then also called embedded or embodied energy, because it is not primarily used as fuel. In explosives and mineral nitrogen fertilisers e.g. the chemical energy could be calculated as part of indirect energy input. If all the energy used up to produce goods and services can be derived from one energy unit, the so called solar energy Joule [sej], the indirect energy is also called emergy spelled with m.

Typical direct energy input sources on farm level are usually a mixture of fossil and renewable energy sources:

1. Fossil: heavy fuel oil, diesel, and light fuel oil, gasoline, natural gas, peat, district heat, and electric grid power from fossil fuels
2. Renewable: earth heat, biogas, electric power from renewable energy sources, wood chips and fire wood, straw, district heat from renewable energy sources.

Because the production of both fossil and renewable energy requires a certain amount of energy input depending on the production technique, every direct energy input item contains also a portion of indirect energy. This portion is taken into consideration by the EROI.

Example. The electricity company lets the farmer know that the farm receives electric power produced from 40 % peat and other fossil energy sources, 34 % from renewable energy sources and 26 % from atomic plants. The EROI of a coal power plant is 8, of a hydroelectric power plant 24 and of a nuclear power plant 5 [Pimentel 2008]. Than the EROI of the electric power producing facilities excluding the thermal conversion efficiency is:

$$EROI_{el} = 0.4 \cdot 8 + 0.34 \cdot 24 + 0.26 \cdot 5 = 12.66$$

This means, that the production of 1 kWh electric power requires for this power mix 1/12.66=0.08 kWh indirect energy for the construction of the power plants. In other words, the electric power input of the farm has to be multiplied at least with the factor 1.08 to include the indirect energy input portion.

6.1 Indirect energy use

The major indirect part of energy in agricultural production is mainly the energy used in machine manufacturing and maintenance and also in buildings. Besides these the farmers buy also chemicals and feed materials. The energy needed in the manufacturing and transportation of these goods is normally allocated to indirect energy usage. The most important input items passing the farm gate are goods or materials, besides services. We group them into:

1. "Living" inputs for crop production processes: e.g. seeds. seedlings.
2. Agrochemicals and minerals for production processes: e.g. mineral fertilisers, crop protection agents, seed dressing agents, drugs, cleaning material.

3. “Living” inputs for animal production processes: e.g. piglets, calves, breeding animals etc.

4. Feed for animal production processes: e.g. feed from outside are concentrates, additives, and forages. Feed produced inside the farm boundary is the output of crop production processes e.g. silage and hay.

5. Investments: farm machinery, tools, buildings used by the farm processes, office equipment. Other indirect energy inputs like precipitation and other natural resources like oxygen from the atmosphere and humus production of the edaphon, human labour and services are often neglected.

6.1.1 Seeds in crop production

Seed is needed to establish the crop production. They can be reserved from the previous yield or they can be bought. In energy calcluations either heating value or energy used in the seed (crop) production could be used. The easiest way to take into account seeds is to subtract their part from the yield. When the yield is sold out from the farm we use the heating value of the seed as output in analysis. If the farm boundaries are the system bounaries and we look the mass and energy flows through the boundaries, farmer’s own seeds stay inside the boundaries. When farmer buys seed and they cross the farm boundary, shall we consider seeds as energy or a product, which ’manufacturing’ energy we include in the analysis the same way we do with machines and chemicals. If the farm boundaries are the place where we make the inventory then the followind procedure could be used:

- When own seeds are used, the amount is subtracted from the yield. Only this amount will go out from the farm.

- When seeds are bought then the energy needed for seed production is used in analysis

This procedure is in line with the system analysis method but it gives two energy values for the crop depending if it is input or output. For this reason the following procedure is recommended.

- If and when part of the yield is used as seed next year, the energy amount needed for the seed production is used in the calculations. The energy output of the whole production is calculated and the energy needed for seed production is subtracted from this.

- When seed is bought the energy needed for seed production is used as input in the calculations.

In the latter method the calculation basis is the same and it does not distort the analysis if the farmer uses own seed or buys the seed.

6.1.2 Agrochemicals and minerals

Usually energy analysis calculations in agriculture take crop protection agents and mineral fertilisers as indirect energy input into account. A glance through the inventory sheets of farms shows, that there are much more agrochemicals and minerals in use. Table 6.1 shows an example:

Agrochemicals are the most energy-intensive agricultural input [Stout]. However, the quantity of active agents is very low and the proportion of the indirect energy input therefore small. It is very difficult to get reliable figures of the energy required to manufacture the agents, their carriers and solvents as well as the energy for packing, transport, distribution, and application. A huge amount of energy input is also required for research and development, testing, safety measurements, legislation, administration, supervision, control of food, feed and fibre for chemical residues, security training, health care and cleaning of environmental pollutions caused by abuse and accidents.

The problem is, where to get reliable energy figures for hundreds of agrochemicals? Only manufacturers can deliver scientifically sound figures, in case they can be verified. Presently near all energy figures for crop protection agents used in literature base on one publication of Green 1987. Based on

Table 6.1: Examples of agrochemicals in agriculture

Agrochemicals in crop production	Agrochemicals in animal production
Pesticides	**Nursing agents**
Fungicides	Cell test lotion
Herbicides	Cetosis-lotion
Growth regulators	pH-lotion
Pheromones	Coal lotion
Artificial fertilisers	Ca-lotion
Diammonium phosphate	Mg-lotion
Ammonium nitrate	Nipple lotion
Urea	**Drugs**
Phosphoric acid	**Cleaning agents**

this figures the calculation from similar chemicals can be done by interpolation. The identification of similar agents grant public databases. The Pesticide Action Network (PAN) Pesticide Database (http://www.pesticideinfo.org/) is a location for toxicity and regulatory information for pesticides and the Compendium of Pesticide Common Names (http://www.alanwood.net/pesticides/. For purposes of trade, registration and legislation, and for use in popular and scientific publications, pesticides need names that are short, distinctive, non-proprietary and widely-accepted). More than 1100 of these official pesticide names have been assigned by the International Organisation for Standardisation (ISO), in accordance with an established system of nomenclature. This Compendium is believed to be the only place where all of the ISO-approved standard names of chemical pesticides are listed. It also includes more than 300 approved names from national and international bodies for pesticides that do not have ISO names".

Many natural minerals are used as fertilisers for crop production, salt is used in animal production. In scientific energy analysis publications energy values of fertilisers are usually calculated on the basis of chemical substances. However, farmers use commercial products and do not know the composition of substances of a certain fertiliser product. In Finland products from Yara International are mainly used and the Finnish product sheets of this company show information about the content of the nutrient only. Although the substances used for the product are registered in the REACH database (REACH is a new European Community Regulation on chemicals and their safe use (EC 1907/2006), it deals with the Registration, Evaluation, Authorisation and Restriction of Chemical substances, e.g.), there is no information available about the proportion of the substances used. Therefore the calculation of the indirect energy input of commercial products is not precise. The following example in table 6.2 highlights the problem.

Table 6.2: Indirect energy input of nitrogen fertilisers in MJ per kg total nitrogen (source: Gaillard et al. 1997)

Substance	Unit	Internal	Process	Production	Handling	Total
Urea	MJ/kg N	28,7	20,5	48,2	14,5	64,8
Ammonium nitrate phosphate	MJ/kg N	30,4	13,7	44,1	10,4	55,5
Ammonium nitrate	MJ/kg N	30,7	9,9	40,6	6,8	48,4
Urea ammonium nitrate	MJ/kg N	29,0	15,3	44,3	10,5	55,8

Table 6.3 shows the indirect energy input value (manufacturing energy value) of the nutrient based on literature data.

Table 6.3: Indirect energy input value of the nutrient based on literature data

Nutrient	Source	Total N	Total P	Total K	Mg	Na	S	B	Zn
		MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg
Energy content	Mikkola & Ahokas 2009	49.2	15.5	9.7					
	Mudahar & Hignett 1987						3.0	18.18	6.9
	Estimated				7.4	7.4			

6.1.3 "Living" inputs for animal production processes: e.g. piglets, calves, breeding animals etc.

The energy content of animals purchased outside of the farm leaves often outside of energy analysis calculations, although this amount may be considerable e.g. in meat production. In living input calculations the same methodology as in seed input can be used (see chapter 6.1.1). According to that only the energy needed for breeding of the piglets and calves etc is included in the analysis. If the heat value is used then farms who breed their own animals are in different positions than farms who buy the living input.

6.1.4 Feed input

Mixed feed is often imported from outside the farm to poultry and pig farms. A great portion of the feed comes from abroad causing the nutrient surplus of many animal farms. For feed input the same strategy must be used as for seeds and animal breeding (living inputs). If two farms are examined, one produces its own feed and the other buys them outside. The first farm input includes only the resources needed for the own production. The second farm, if he uses the heating values (energy values) for input is in much worse situation and the figures would not prevail the production efficiency in this case. If we want to compare energy efficiencies of the farms, then we should use for bought feed (input) the feed material production values, not the heat values.

6.1.5 Investments: farm machinery

"Indirect energy input is relatively easy to identify but difficult to analyse. This is a common problem in energy analysis. Single indirect energy items are often small so they are considered insignificant and are neglected. Although they are significant as a whole, there is no easy way to analyse them. A life cycle assessment or corresponding procedure is often considered too laborious for this purpose. Thus indirect energy input is usually assessed either not at all, or only as a percentage of the total energy consumption. For example, a common procedure is to calculate repair and maintenance costs as a percentage of purchase costs, and then apply the same percentage to the manufacturing energy input to estimate the maintenance energy input" [Mikkola and Ahokas 2010].

The indirect energy input of farm machinery embraces the energy for production of the raw material, manufacturing of the machinery, repairs and maintenance of the machinery (outside the farm) and transport from the factory to the farm. Maintenance like lubrication services is usually done on farm and the fossil energy input in form of lubricants is accounted for direct energy input.

Usually farm machinery is produced from steel; however vehicles contain about 5 % rubber materials. The proportion of different types of direct energy input sources determines the production energy of steel. Table 6.3 shows an example.

Table 6.4: Indirect energy input and energy resources of farm machinery manufacturing and repair and maintenance.

	MJ/kg	Energy sources	Reference
Steel production energy			
Steel	33	Heavy fuel oil: 53 % Electric power: 24 % Natural gas: 17 % Diesel: 6 %	[Gaillard et al. 1997] after [Weidema and Mortensen 1995]
Steel	24	Swedish steel	[Mikkola and Ahokas 2010] after [Börjesson 1996]
Steel	22.5		[Mikkola and Ahokas 2010] after [Farla and Blok 2001]
Steel	8.5	recycled steel and iron	[Mikkola and Ahokas 2010] after [Farla and Blok 2001]
Rubber production energy			
Rubber	23.4	Heavy fuel oil 100 %	[Gaillard et al. 1997] after [Cowell et al. 1995] after [Guelorget et al. 1993]
Agricultural machinery manufacture energy			
Tractors Other vehicles Tillage implements Other machinery	14.6 12.9 8.6 7.4	Heavy fuel oil: 26.5 % Electric power: 62 % Natural gas: 8.5 % Diesel: 3 %	[Gaillard et al. 1997] after [Doering 1980]
Agricultural machinery repairs and maintenance			
Tractors Other vehicles Tillage implements Other machinery	12.2 10.4 12.3 10.4	26 % of energy 23 % used for 30 % material 26 % and manufacturing	[Gaillard et al. 1997] after [Mughal 1994]
Plough. Chisel Plough. S-tine harrow. combined drill. direct drill. roller. field sprayer mounted	24 to 85	37 to 97 % of manufacturing energy	[Mikkola and Ahokas 2010] after [Fluck 1985] and [Bowers 1992]
Transport			
Transport factory to farm	1.2	100 km rail. 400 km road	[Gaillard et al. 1997]
Transport factory to farm	8.8		[Mikkola and Ahokas 2010] after [Loewer et al. 1977]

The weight of machinery times the energy conversion factor of mass to energy describes the indirect energy input of farm machinery for the life time of the machinery. Because agricultural machines are used many years for different production types (crop production, animal production, transport, farm maintenance work) and widely diverging working times per year, the allocation of indirect energy input of farm machinery is difficult. “There is no exact lifetime for agricultural machinery. It depends on usage, level of service, and speed of technical and economical development. If development goes fast, machines become obsolete or uneconomical sooner than they are technically worn out. For instance, in Denmark [Bak et al. 2003] the average annual usage was over 200 h. Results from Finnish farms [MTT 2005] support the Danish results. The newest tractors are used more than the average during the first 5–7 years, but after that period usage declines. After 15 years the usage is only 100 h. In order to achieve the estimated technical lifetime usage tractors should be running for 40–60 years, while the estimated economic lifetime is only 10–15 years. It would be important to know the real lifetime usage because there is a large difference depending on whether the manufacturing energy is allocated for 3 000 h or 16 000 h. This same problem relates to implements and agricultural buildings as well" [Mikkola and Ahokas 2010].

We assume that the physical boundary of the farm is the system boundary too. That means, only in the year of purchase the farm machine is crossing the boundary and fills the "stock" of the farm machinery tank within the system. Indirect energy is consumed every time the machine is used until the end of the lifetime. Then usually the machine is disposed as waste and only the energy content bound in steel and rubber leaves the farm boundary. Therefore the exact calculation of the indirect energy input of farm machinery is possible only after the end of it's life cycle. The matter comes more complicated when the lifetime of a machine is not used completely at the farm but is is changed to a newer machine without utilizing its whole lifetime. Depending on the purpose of the energy analysis different approaches are possible to solve this problem:

1. Top down approach depreciating the lifetime of the farm machinery according to the national bookkeeping rules on financial depreciation. In Finland the accelerated depreciation is presently up to 25% per year [Finlex 1967]. Advantage: The strong deprecation of new machinery correlates well with the actual use. Disadvantage: Comparison between different farms in different years and in different countries is not possible

2. Top down approach using fixed lifetime and straight-line or linear depreciation depending on the purchase value. Adavantage: Simple to calculate and comparable results. An example, how this method can be applied for tractors and vehicles using the technical lifetime in operating hours shows the wide range of possible indirect input figures. We can use the equation derived from [Mikkola and Ahokas 2010][1]:

$$q_{indir} = \frac{(-0.1027 \cdot P_N + 66.692) \cdot E_{ind} \cdot 1000}{H_{fuel} \cdot t_l \cdot q_s(\lambda, n) \cdot \lambda} \tag{6.1}$$

   q_{indr} = indirect energy input in % of tractor fuel consumption in litres
   P_N = rated power in kW
   E_{ind} = indirect energy input for material, manufacturing, and transport of the tractor to the farm in MJ/kg
   H_{fuel} = LHV of diesel fuel in MJ/kg
   t_l = tractor lifetime in hours
   $q_s(\lambda, n)$ = specific fuel consumption (depending on engine load rate λ and engine speed n) in g/kWh
   λ = engine load rate in % of P_N

   The large number of parameters makes it difficult to give a precise value for the indirect energy consumed by one litre of fuel consumed. But an average of 20 % seems to be a reasonable calculation basis as the figure 6.1 shows.

3. Bottom up approach: Recording the real tractor hours at least for each year and where possible allocation to crop production, animal production, transport, and farm estate work. This requires lifetime estimation on either operating hours (e.g. 12 000 h) or years of operation (e.g. 20 years).

   Example: A tractor operating a harrow consumes 10 litres per ha, that is about 356 MJ/ha. With 20 % indirect energy (see figure 6.1), the tractor uses up an indirect energy portion of

[1] the item $-0.1027 * P_N + 66.692$ describes the tractor weight depending on engine rated power. The data origin from [Mikkola and Ahokas 2010].

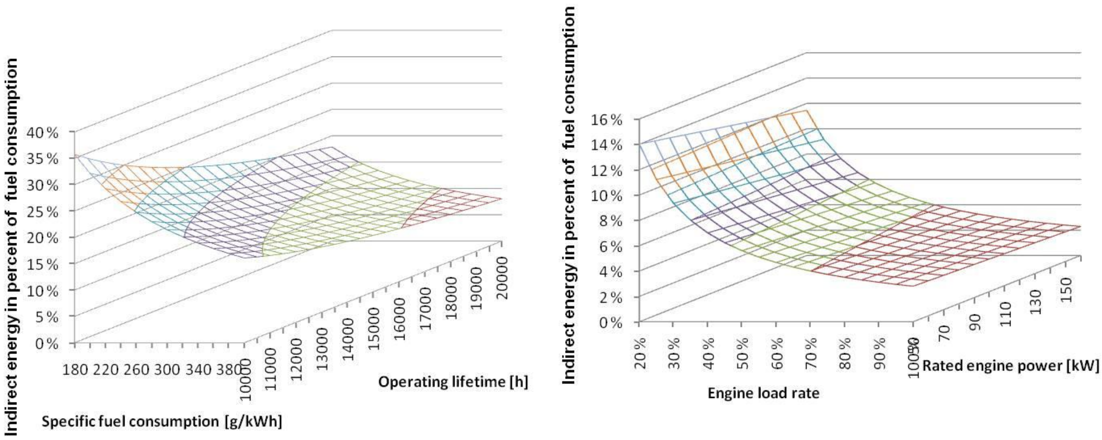

Figure 6.1: Indirect energy input in % of tractor fuel consumption. The constant parameters for the left hand side diagram are: engine rated power $P_N = 60\,kW$ and engine load rate $\lambda = 0.3$. The constant parameters of the right hand side diagram are: tractor lifetime $t_l = 20\,000\,hours$ and specific fuel consumption $q_s(\lambda, n) = 350\,g/kWh$

$356 \cdot 20\,\%\,MJ$, all together 472.2 MJ/ha. The indirect energy for a plough of 1 000 kg mass is $1000\,kg \cdot 6.74\,MJ/kg = 6.74\,GJ$ (see table 6.4). Than we have to add for ploughing e.g. 100 ha arable land per year 67.4 MJ/ha and year. That is all together 540 MJ/ha direct and indirect energy for ploughing one ha.

4. Comparable mode approach: normalising the calculation to make indirect energy inputs of different farms in different years comparable.

   Method 1: 144 MJ/kg over 10 years linear depreciation after Nyholm et al [**?**] and after Conforti And Giampietro [Conforti and Giampietro 1997] and after Stout [Stout 1991].

   Method 2: Indirect energy values after [Gaillard et al. 1997] (see table 6.5) and linear depreciation over 20 years as shown in table 6.5 below. The main advantage of this source is that also the conversion factors for emissions are available and the figures of total energy are in line with the findings of [Mikkola and Ahokas 2010].

6.1.6 Investments: buildings

Usually the indirect energy use of buildings is calculated on base of a life cycle analysis that estimates the energy input for construction material (raw material extraction and recycling of post-consumer and post-industrial materials, manufacturing), transport of the material, construction site preparation and initial building construction, maintenance (including building operation like heating and lightening energy, electric power, water and sewage, ventilation), material decommissioning and demolition, recycling of building materials and land-filling of building materials. The total energy is the sum of all the energy used by a building during its life cycle (total embodied energy plus operating energy). This figure is then divided by estimated lifetime and the gross area of the building or the gross volume of the building respectively. Because there are no standards in calculation methods and terminology, the following approach could be used:

1. Building materials including extraction, processing of recycled materials, transport.

2. Construction (alias production, erection, connection, and so on) of the building including site preparation, work, and transport to the site. The initial embodied energy is the sum of the energy embodied in all the material used in the construction phase, including technical installations.

Table 6.5: Indirect energy input of agricultural machinery in MJ/kg and year assuming 20 years linear depreciation

Machine	Indirect energy input MJ/kg	MJ/kg and year 20 years linear depreciation
Material		
Tractors	71.4	3.57
Other vehicles	71.4	3.57
Tillage implements	71.4	3.57
Other implements	71.4	3.57
Production and processing		
Tractors	63.8	3.19
Other vehicles	56.4	2.82
Tillage implements	37.6	1.88
Other implements	32.4	1.62
Repair and maintenance		
Tractors	40.4	3.57
Other vehicles	34.4	1.72
Tillage implements	40.7	2.04
Other implements	34.2	1.71
Transport		
All Implements	1.2	0.06
Total		
Tractors	176.8	8.84
Other vehicles	163.4	8.17
Tillage implements	150.8	7.54
Other implements	139.1	6.96
Total including steel recycling		
Tractors	160.8	8.04
Other vehicles	157.4	7.37
Tillage implements	134.8	6.74
Other implements	123.1	6.16

3. Maintenance (alias operation, renovation works, repair, rehabilitation, and so on) of the building including repairs (material, energy, work, waste, transport to and from the site). The recurring embodied energy is the sum of the energy embodied in the material used in the rehabilitation and maintenance phases.

4. Demolition of the building including transport, dumping, and waste treatment.

5. Operating energy: Energy used in buildings during their operational phase, as for heating, cooling, ventilation, hot water, lighting, and other electrical appliances. It might be expressed either in terms of end-use or primary energy. Primary energy is measured at the natural resource level. It is the energy used to produce the end-use energy, including extraction, transformation and distribution losses.

We do not allocate the operating energy (alias direct energy input, water and sewage, ventilation, and so on) to the indirect energy input of buildings, to avoid double counting of direct energy sources passing the farm boundary. The operating energy input depends widely on the purpose of the building, technical equipment and facilities installed, the number of humans or animals using the building, weather conditions, and geographical location making reasonable comparison impossible. However, there is a linear relation between operating and total energy [Satori and Hestnes 2007] despite climate and other background differences. Depending on the calculation method applied the indirect energy input ranges between 10 and 20 % of the total energy input, see table 6.6. The figure of 153 MJ/m^2 and year for construction and demolition seems to be reasonable for agricultural buildings and is in line with the figures of the other authors

Table 6.6: Direct and indirect energy input for buildings

Type of building		A	B	C	D	E	F	G
Unit	Lifespan years	40	50	50	58	58	59	80
	Construction	9.0	6.0	3.7	-	-	-	11.1
	Maintenance	1.5	3.9	1.5	-	-	-	-
GJ/m^2	Demolition	0.5	0.1	0.1	-	-	-	1.1
	Total embodied	11.0	10.0	5.3	6.4	5.1	5.3	12.2
	Operating	48.4	54.6	41.7	42.8	45.9	42.7	21.3
	Total	59.4	64.6	47.0	49.2	51.0	48.0	33.6

Type of Building

A Mean of ten office buildings 1 253 to 22 982 m^2 in Japan after [Suzuki and Oka 1998]

B Detached house 135 m^2, 410 m^3 in Finland after [Saari 2001] p. 11

C Block of flats 2447 m^2, 7800 m^3 in Finland after [Saari 2001] p. 17

D Mean of 46 residential buildings 50 to 1 520 m^2 after [Ramesh et al. 2010]

E Mean of 6 concrete residential buildings 94-1 190 m^2 after [Ramesh et al. 2010]

F Mean of 32 wood residential buildings 94-1 190 m^2 after [Ramesh et al. 2010]

G Agricultural buildings after [Gaillard et al. 1997] including material and transport. Data sources originate from life cycle analysis of reports, not from reviewed articles. The authors allocated 266.4 MJ/m^2 and year to maintenance. We allocate this figure to operating (direct energy input).

7 Energy use and resources in Estonia and Finland

Biomass is a good method to store renewable energy for winter period when energy demand is the highest. There is not visible such solar and wind energy solutions which would guarantee an even and undisturbed energy supply all over the year. Wind would be a clean energy source but the highest average wind speeds are significantly lower than e.g. on the best zones in Denmark, Holland, Germany, and United Kingdom. Additionally, wind power requires reserve power for calm periods.

Hydro power would be ideal reserve for wind power but its availability is limited. For these reasons biomass based energy sources will be needed on a way to cleaner and more sophisticated energy service. Biomass can be harvested from forests, fields or waters. Peat originates from biomass but it is classified as fossil fuel due to its long renewing time. Field biomass is the least biomass sources available but it is not insignificant. In the future, if energy will be a scarcity commodity, all energy resources will be important, energy prices will rise, and earlier uneconomical energy sources will be employed.

7.1 Energy use and resources in Finland

7.1.1 Peat

The United Nations Framework Convention on Climate Change (UNFCCC 2004) and The European Union (EU 2006) have defined peat as a fossil fuel. Finland has more mires and peat lands regarding its land area than any country in the world; one third of our total land area is covered with them [Korhonen et al 2008]. Milled peat is used in power plants and sod peat in small-scale use on private residential houses and farms.

Virtanen et al. [Virtanen et al 2003] have estimated the technically exploitable peat resources to be 12 800 TWh. This is 31 times the primary energy consumption in Finland in 2007 (408 TWh) [Energy consumption 2007]. Annual growth is 37 TWh and the consumption has varied from 17 TWh to 28 TWh [Peat consumption] in the 2000's.

7.1.2 Wood

The reserve of unbarked stem wood was in Finnish forests 2201 milj. m^3 in 2008. The annual growth was 99 milj. m3 [Forest resources]. The reserve equals to 4352 TWh energy and the annual growth to 198 TWh. The annual removal (fellings and natural losses) over the last five years have been 70% of the average increment during the same period [Forest resources]. Wood reserves are also growing because the annual removal is less than growth. Forests produce also harvesting residues, stumps, and small diameter thinning wood which can be used for energy. Wood can be used in different forms such as waste liqueurs, bark, saw dust, wood chips, pellets, and firewood. Pulp and paper industry produces energy from wood by combusting black liquor and other concentrated liqueurs (35 - 43 TWh per year). Bark, forest chips, and sawdust are also widely used for power and heat production (23-29 TWh per year). Small scale combustion of wood as fire wood and chips has been steadily 13-14 TWh per year. [Statistics Finland 2009] A techno-economical estimation of the potential of wood energy made by Maidell et al. [Maidell et al 2008] includes energy from harvesting residues, stumps, and small diameter thinning wood. When uneconomical harvesting areas and areas with low energy yield have been excluded the techno-economical potential is 23,5 TWh. Laitila et al. [Laitila et al 2008] estimated also the techno-economical potential of wood biomass for energy. Their estimation excluded round timber and its residual fractions used in pulp and paper industry and sawmills. The estimated wood biomass resource was 15,9 milj. m^3 and equalled to 32 TWh energy. When the share of forest chips (5,2 TWH) and wood in small scale combustion (4 TWh) in use is subtracted the real net increase could be about 23 TWh.

Short-rotation willow could produce woody biomass on fields. However willow cropping has not caught any favour worth mentioning in energy production despite research efforts in Finland and especially in Sweden [Heino et al 2005]. In Sweden the cropping area was 13 700 ha in 2009. It is remarkable that the cropping area was not increasing but fell 3% from the previous year [Jordbeuksstatistik 2010]. Probably for its low economic competitiveness willow production has not gained any wider position as an energy crop.

7.1.3 Agrobiomass

Agrobiomass is a common name for a heterogenic group of biomass originating from agriculture. Agro biomass is grown on fields and it is fed to animals or used in food industry. Manure and straw are the biggest available biomass resources . There is also spoilt fodder, tops of sugar beet, peeling waste, process waters, whey, distiller's wet grains and corresponding biomass that contains compounds usable in energy production. Energy crops are a group of their own. These crops should produce biomass with high energy ratio and low input. The long term climate and energy strategy of Finland states that we have 500 000 ha of field that could be used for other purposes than food and fodder production e.g. for bio energy production [Ilmasto ja energiastrategia 2008]. The quality of bio energy crops varies in wide range depending on which plants are grown and at which growth stage the crop is harvested. Dry biomass with low ash and alkali metal content is good for combustion, starch and sugar suit for ethanol production, vegetable oils for bio diesel production and slurries containing carbohydrates and lipids can be used for biogas generation. Agro biomass is often used together with wood, peat or slurry in energy production because co-generation brings energetic or environmental advantages.

7.1.4 Reed canary grass

Finnish fields are mainly used for producing of food for people and fodder for animals. The cultivation of reed canary grass for energy generation grew fast in the beginning of the 2000's [TIKE 2007]. The Figure 7.1 presents the development of the cultivation area in the period 2001 – 2009. The fast growth was followed by a decline in 2008 – 2009. Despite the fast growth the acreage of reed canary is still minor, less than 1% from the total field area. At the background of the increased area was demand from bio power plants and economical competitiveness with other crops. Economical competitiveness was based mainly on farming subsidies but not on high product prices on the market. When prices of cereals doubled in 2008 farmers were no more interested in to increase the area of reed canary grass. After 2008 cereal prices have gone down but interest in reed canary grass has not recovered. Reed canary grass is so far the only energy plant grown on fields and the only energy plant which has economic meaning.

Reed canary grass yields the best field biomass energy ratio in Finnish conditions and the net energy yield is as high as that for sugar beet [Mikkola and Ahokas 2009]. Reed canary grass is also easy to cultivate and harvest. Average dry matter yields in practical farming rise to 5 – 6 Mg ha^{-1}. It is not a very high yield compared with yields of corn, miscanthus giganteus or sugar cane grown on more southern areas. However, trials with corn have shown that C4 plants do not adopt in cool Finnish climate. Reed canary grass has proved its competitiveness in Finnish conditions in terms of high dry matter yield and cultivation properties. In 2007 the cultivation area of reed canary grass was 19 000 ha [TIKE 2007] and the energy yield was 0.5 TWh. If all surplus field, totally 500 000 ha, would be allocated for reed canary grass the energy yield would equal to 12.2 TWh.

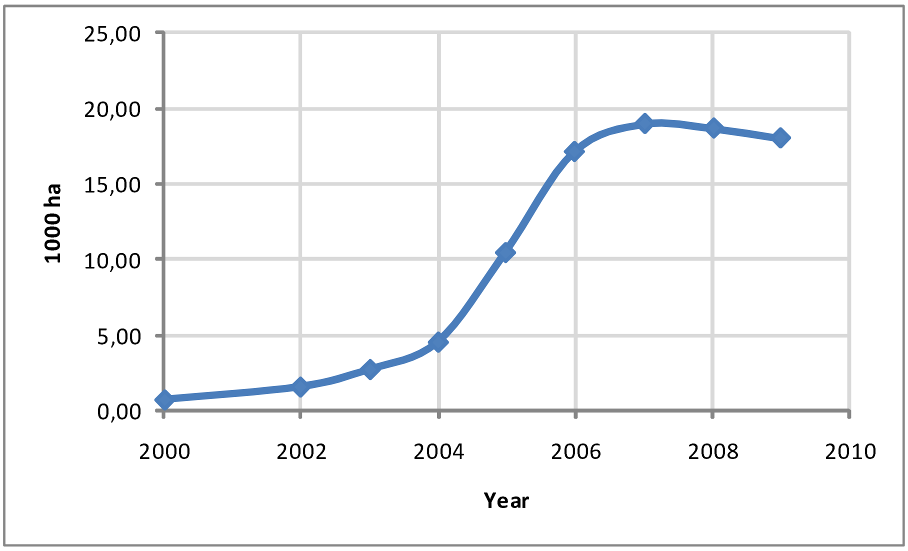

Figure 7.1: Development of reed canary grass cultivation area

7.1.5 Straw

Straw is mainly an unused biomass resource in Finland. As a by-product of cereal production it is in most cases chopped and left on the soil surface. Only 20% of straw is used for animal bedding and 6 milj. kg for energy [MMM 2004]. After the first oil crises in the 1970's Ahokas et al. [Ahokas et al 1983] evaluated the technical potential of straw energy. Ahokas et al. anticipated that after subtracting straw for bedding and fodder, 2/3 of the straw yield could be harvested. The lower heating value of the dry matter was assumed to be 12.4 MJ/kg in the moisture content of 25%. Thus the heating value of the whole yield was evaluated to be 7.6 TWh. Another expert group estimated possibilities to increase the use of bio energy till the year 2015. According to this group the energy content of straw is about 10 TWh [KTM 2007a]. Because 20% of the straw yield is exploited the unused potential is 8 TWh.

7.1.6 Energy from agro waste

Manure is a potential resource for energy generation. Biogas process suits well for processing wet waste materials. Liquid digestion can be used for slurries with dry matter content below 13% and dry digestion for manure with 20 – 35% dry matter content. Other methods like combustion or heat recovering from compost are technically possible but they have not gained economical meaning. A working group of the Ministry of Trade and Industry considered possibilities to execute a feeding tariff for electricity produced from biogas and this working group estimated that the total amount of manure corresponded to 1.5 TWh as energy. This was a theoretical potential and after taking into consideration practical and economical restrictions the working group concluded that the technical potential of manure was 0.4 TWh [KTM 2007b].

7.1.7 Summary of biomass resources

Table 7.1 summarises the potential of Finnish biomass resources. One criterion for sustainable usage of biomass is that biomass is used in maximum as much as or less than the biomass renews. This is why the maximal potential is related to the annual growth in 7.1. Wood is the most significant biomass fuel in use. Peat is the second important domestic fuel but it is classified as fossil fuel. The unused potential of agro biomass is in maximum the same magnitude as that for wood and peat. If the maximum potential of agro biomass will be exploited more than every fifth field hectare will be allocated for energy crop and straw yield is exploited maximally. Though energy from biomass is an important player from the national point of view there is no chance to base the Finnish energy service totally on biomass. Private households and farms which own forest and field could be self-sufficient in energy or even energy positive. They could process biomass into energy products and sell them outside the farm. Price relations between bio energy products and other energy sources will largely work out which kind of bio energy will be mainly used.

Table 7.1: Finnish biomass resources related to annual growth or production (manure)

Bio mass	Maximum potential TWh	In use TWh	Unused potential %
Peat	37	17 - 28	24 - 76
Wood[1]	105	82	22
Reed canary grass[2]	2 - 12	0,5	75 - 96
Straw	8	0	100
Manure	1,5	0	100

1) Only residual biomass, which is not exploited in pulp and paper industry and saw mills is considered
2) Estimation of the area vary from 100 000 to 500 000 ha

7.2 Energy use and resources in Estonia

The main purpose of the fuel and energy sector in Estonia is to supply the country with high quality fuels, electricity and heat and to ensure the optimal functioning and development of the fuel and energy sector. The main task is to reduce the negative environmental impact of energy sector, to enhance the efficiency of energy production and consumption, and to increase the use of renewable energy sources.

The National Long-term Development Plan for the Fuel and Energy Sector Until 2015 that was approved by the Government of the Republic in December 2004. On the basis of this document, a new National Energy Efficiency Programme for 2007–2013 (which takes into account objectives set by Directive 2006/32/EC) has been prepared. It is estimated in the Programme that a total of 96.0 MEUR is needed during the period of up to 2013 for investments.

For promoting the use of biomass and bio-energy, the Government has approved (in January 2007), the Development Plan 2007–2013 for Enhancing the Use of Biomass and Bio energy. The objective of the plan is to create favourable conditions for the development of domestic biomass and bio-energy production. Additionally, preparations have been started for compiling a national renewable energy action plan. This is a requirement for all EU member states according to Directive 2009/28/EC.

The National Development Plan for Energy Sector until 2020 was passed by the Parliament in June 2009. The most general measurable target of the plan is the gradual reduction of primary energy use (total primary energy supply) which in 2007 was 124.44 PJ. For several measures, target level indicators have been set. As for other targets related to emissions, it has been established that the losses in electricity and district heating networks must have a declining trend from the current level – in 2007 the average losses had been 11.1% and 10.6% respectively. The amount of state expenditures on the activities planned will be approximately 2045 MEUR until 2020.

The transposition of provisions of Directive 2002/91/EC into Estonia's legislation was completed by January 1, 2009. The main provisions were introduced to make relevant amendments in the Building Act and in the Energy Efficiency of Equipment Act. The objective of these amendments was to introduce the energy auditing and labelling of buildings, to improve the energy performance of new and existing buildings, and to provide the users of buildings with an easier access to information about the building's energy consumption and energy saving measures.

The domestic fuels are dominant to meet the need for energy. The most essential domestic energy resources are oil shale, peat and wood. There are unique and long term experiences in oil shale processing and utilisation for energy purposes in Estonia. The two largest oil shale fired power plants produce the major part of electricity in Estonia. The largest enterprise active on energy market is state owned company Eesti Energia AS. In 2009, oil shale accounted for 61% and peat and wood in total – 15% of the total primary energy consumption .

The main imported fuels are engine fuels and gas. Estonian enterprises export shale oil, peat briquettes, wood pellets and electricity. Although the domestic resources of fossil fuel are large enough covering the domestic energy needs for the next decades more attention is paid to utilisation of alternative, including renewable, energy resources in recent years. In 2009 the share of renewable energy sources in the total primary energy consumption amounted to approximately 14%, wood fuels comprised the main portion thereof.

The local business sector's decreasing demand triggered a decline in electricity production. In 2009, the production of electricity totalled 8779 gigawatt-hours – nearly 17% less compared to 2008, [Statistics Estonia]. The local business sectors decreasing demand triggered a decline in electricity production.

Although the proportion of wind and hydro energy is still relatively small in gross electricity generation – less than 3% of electricity output, – a considerable development took place in this sphere in 2009. Due to the new installed wind turbines, the wind energy production increased by about a half compared to the earlier year (47%), the production of hydroelectricity increased by nearly 10%. Using renewable energy sources is subsidised in Estonia. For example, using fire wood or wind for producing electric energy is subsidised by 5.4 euro cents per kWh. In comparison with other EU Member States, the total electricity production in Estonia is small, but the generation of electricity per capita (6.5 megawatt-hours in 2009) is at the EU average level. In Estonia electricity production per capita is bigger than in other Baltic Republics.

In order to reduce the negative environmental impact caused by the waste-intensive oil shale energy, Estonia together with other EU Member States have set a priority to promote electricity produced from renewable energy sources. Directive 2001/77/EC of the European Parliament and Council on the promotion of electricity produced from renewable energy sources sets national indicative targets for Member States. The referred national targets are required to be achieved in 2010 at the latest. The relevant indicative target for Estonia requires that 5.1% of electricity in the total electricity consumption should be generated from renewable sources. In Estonia, renewable energy is generated from hydro- and wind energy and from biomass. In 2008 the share of electricity generated from renewable sources was only 2.1% in the total electricity consumption, but in 2009 due to the new wood fuel based combined electricity and heat generation power plants this indicator increased to 6.1%.

By the renewed Directive 2010/31/Eu Of The European Parliament And Of The Council of 19 May 2010 [DIRECTIVE 2010/31/EU] on the energy performance of buildings, the energy performance of buildings should be calculated on the basis of a methodology, which may be differentiated at national and regional level. That includes, in addition to thermal characteristics, other factors that play an increasingly important role such as heating and air-conditioning installations, application of energy from renewable sources, passive heating and cooling elements, shading, indoor air-quality, adequate natural light and design of the building. The methodology for calculating energy performance should be based not only on the season in which heating is required, but should cover the annual energy performance of a building.

Minimum requirements for the energy performance of buildings stated by government regulation No 258 20 December 2007 are valid since 01 January 2008 [Energiatõhususe miinimumnõuded]. In January Software in Estonian BV2 came out for calculations of meeting the minimum requirements for the energy performance of buildings. Order and form of The energy performance certificate stated by regulation of Minister of Economic Affairs and Communications No 107 17 December 2008 valid since 01 January 2009 [Energiamärgise vorm ja väljastamise kord]. The minimum energy performance requirements for buildings or building units are not set to the following categories of buildings:

(a) buildings officially protected as part of a designated environment or because of their special architectural or historical merit, in so far as compliance with certain minimum energy performance requirements would unacceptably alter their character or appearance;

(b) buildings used as places of worship and for religious activities;

(c) temporary buildings with a time of use of two years or less, industrial sites, workshops and non-residential agricultural buildings with low energy demand and non-residential agricultural buildings which are in use by a sector covered by a national sectoral agreement on energy performance;

(d) residential buildings which are used or intended to be used for either less than four months of the year or, alternatively, for a limited annual time of use and with an expected energy consumption of less than 25 % of what would be the result of all-year use;

(e) stand-alone buildings with a total useful floor area of less 50 m^2.

By 2009 2396 the energy performance certificate were given out including 165 for new and 2231 for existing buildings.

7.2.1 Agricultural land use

The total area of Estonia is 45 227 km2, including 43 698 km2 of land area. More than a half of the land area is forest land, one-third is agricultural land, and one-fifth is covered by mires and bogs. A rapid decline in agricultural land use has occurred in Estonia since the restoration of independence in 1991. The scale of this decrease in arable land was the most drastic change in the whole of Europe, and was higher than other post-Soviet European countries. The use of abandoned agricultural areas is considered as one potential way of increasing bio-energy production. In 2007 there were about 840 thousand hectares fields that was covered by Common Agriculture Policy (CAP) subsidies and 286 thousand hectares without applications of which entirely abandoned field parcels formed 123 187 hectares (on 49 190 fields). Consequently about 163 thousand hectares are located on fields which are partially in use. The total abandoned agricultural land is about 430 thousand hectares but from that 144 thousand hectares are outside of Agricultural Registers and Information Board´s (ARIB) field parcels. There are about 94 thousand hectares grasslands and 52 thousand hectares fields that are deducted from ARIB‘s databases. CAP subsidy applicants, who don't have any livestock units owned 136 thousand hectares grasslands of which 51 thousand hectares are in farms where grassland forms 100% of total land use [Astover]. The Statistics Estonia recorded 23 300 agricultural holdings 2007 in Estonia, which represents a 16 % decrease since 2005 and 59% decrease since 2001. This drop is accompanied by an increase in the utilised agricultural area, reflecting the decrease in the number of small farms together with the increase in the number of large ones.

When 2001 small (<20 ha) holdings formed 89% of total agricultural holdings and used ca 30% of total agricultural land then in 2007 the proportions were 76% and 13% (figure 7.2). Holdings over 100 ha formed 1.8% of total and used ca 49% of land. In 2007 70% of arable land was managed by 6.7% of holdings.

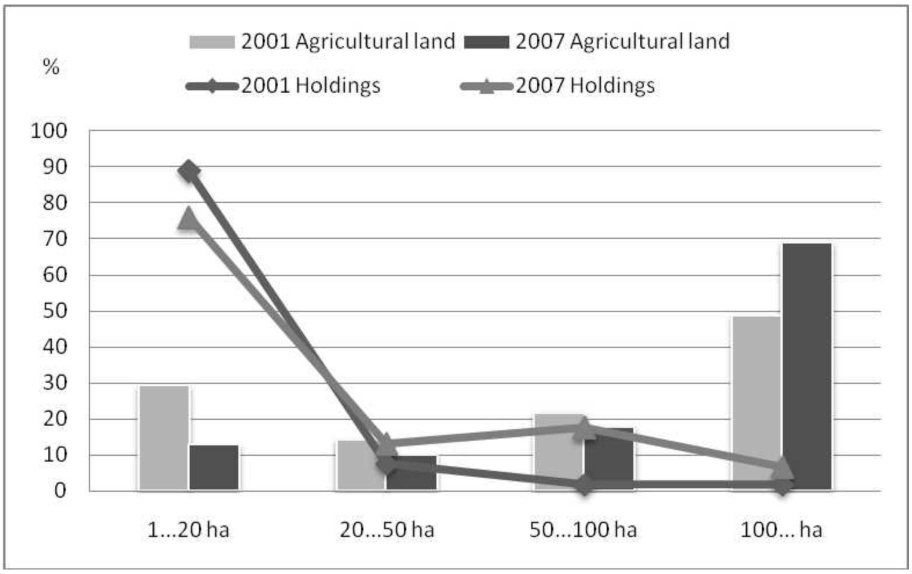

Figure 7.2: Distribution of the utilised agricultural area in proportions of total, 2001 and 2007 Source data: Statistics Estonia, 2010

In recent years cereal growth area have been ca 20% and total yield 10% lower than that in 1980´s. In 2009 cereal and rapeseed growth area was 397,5 thousand ha wihch is close to 1980. Rapeseed production is new in Estonia. In 2004 there was about 50 thousand ha under rapeseed plantings then in 2009 the area was about 82 thousand ha. Cultures which have higher yields and give higher prices push avay less compting cultures. Total crop yield increase is highly based on yield increases per ha [Statistics Estonia].

1980...1990 there was an increase in cereal yields but after independence and agricultural reform average yields decreased and in 1999 were the lowest (spring cereals about 1200 and winter cereals about 1500 kg ha-1) in observed period. There have been increasing trend in cereal yields from year 2000 which can be explained with use of higher input amounts. By 2007 average winter cereals yield was about 3900 kg ha-1 and spring cereals 2800 kg ha-1. Rapeseed yields show also increasing trend during the period it is grown wider in Estonia.

Based on the results of variety comparison experiments, the yield of cereals in agricultural enterprises and on farms makes up 40–50% and the yield of potato makes up 35-40% of the potential yield. Analysis of the competitive ability of Estonian agriculture as well as of the changes that have taken place in production reveals that the productivity of the main field crops is relatively low.

7.2.2 Fertilizers

When until 1950s the energetic expenses spent for plant production process by man were relatively small, then nowadays, in connection with the intensification of agriculture, the share of energy used for application of fertilizers, pesticides machinery and equipment has increased several times, depending on the development level of one or another country as well as on the particular crop and the agrotechnology of its cultivation.

As a result of large-scale use of chemicals in fields and intensification of socialist agriculture, which started in the 1960s-1970s, the production of animal husbandry increased to a great extent. Since Estonian agriculture was entirely directed to animal husbandry, there appeared shortage of local fodder. Approximately 25% of milk and 50% of meat were produced at the expense of imported feed. Such forced agriculture led to considerable deterioration of the environment, which was further accentuated by application of fertilizers. In 1970-s and 1980-s the Estonian arable soils were strongly affected by intensive fertilization, which caused also eutrophication of watersheds. In the beginning of 1990-s, after the collapse of the system of collective farming and the decline in the agricultural production, the state of watersheds started to improve. Eutrophication was slower and the nitrogen content in the water of lakes decreased. Due to the improvement of economic situation it is expected that the use of fertilizers and plant protection products will rise but still staying considerably lower than the EU average [Estonian Rural development Plan].

Use of fertilizers increased in Estonia up to the late 1980s. The amount of mineral nitrogen fertilizers applied per hectare of arable land in that period was more than 100 kg N ha-1, while the respective amounts of phosphorus and potassium fertilizers were 26 kg P ha-1 and 75 kg K ha-1, respectively (figure 7.3). The amount of applied organic fertilizers was up to12 t ha-1. Application of fertilizers decreased drastically in the last two decade. The amount of organic fertilizers used in last years is about 3 t ha-1. Compared with the other European countries, the level of fertilization in Estonia is among the lowest. In recent years the use of mineral fertilizers is slightly increasing. As the decline in animal production has not yet entirely stopped, the decreasing trend in the application of organic fertilizers is continuing.

For period 1992–2009 we have calculated the physical amounts of used mineral fertilizers to the energy (figure 7.5). As the information about the properties of organic fertilizers is not available then only mineral fertilizers were converted to energy values. Fertilizers use in arable land has changed after independence. If in 1992 1.9 GJ of nitrogen, 1.3 GJ of phosphorus and 0.7 GJ of potassium per hectare a year was taken to the soil with mineral fertilizers, in 2009 the respective figures were 1.7, 0.4 and 0.2 GJ ha-1 year (figure 7.5). The first half of the period was decline in every nutrient use. 2003 and 2004 and from 2008 the use of nitrogen fertilizers remained on the same level or even increased,

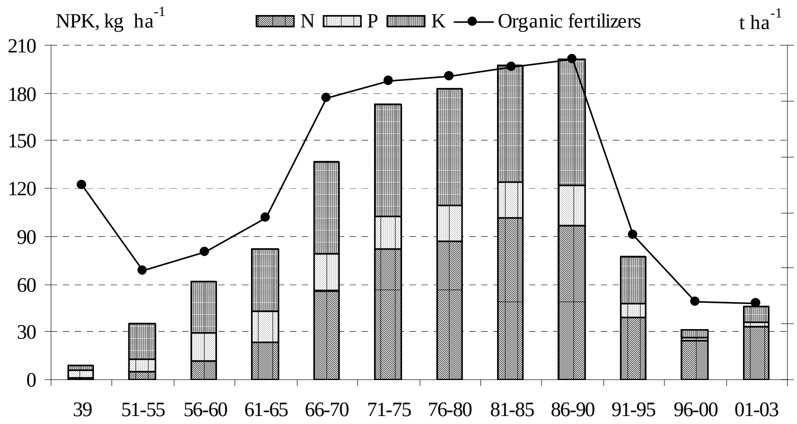

Figure 7.3: Application of mineral and organic fertilizers in Estonia, 1939–2003

as compared with the year 1992.

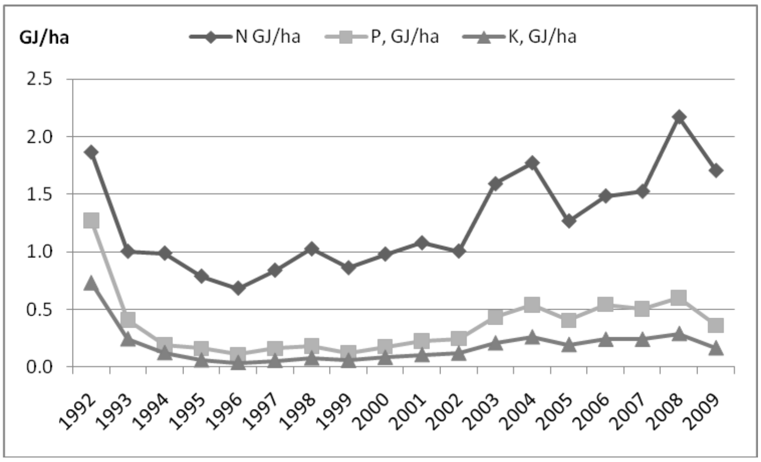

Figure 7.4: Mineral fertilizer use dynamics in Estonian agriculture 1992...2009, GJ ha-1 Source data: Statistics Estonia, 2010

At the beginning of 21 century use of mineral P and K have started to increase which is important in situation where the amounts of organic fertilizers as P and K source are inconsiderable. In Soviet time the animal husbandry was in high spot, and manure/slurry amounts average per ha were considerable compared to mineral fertilizers. Nowadays decrease in mineral P and K use is more harmful to soil quality. As market situation (input and output prices) dictate farmers decisions, then recent years fertilizer use has been very fluctuating.

Mineral fertilizers are the highest energy input in modern intensive agricultural plant production systems. In Germany different research trials have concluded that mineral fertilizers count up to 35...50% of total input (Hülsbergen et, al., 2000; Küsters, Lammer, 1999). Total used mineral nutrient resources in energetic value (GJ) are given in figure 7.5. Decrease has been higher in P and K than in the case of N use.

7.2.3 Pesticides

The use of pesticides shows increasing trend from 1997 to 2009 (figure 7.6). Despite of that is the amount of pesticides used in Estonian agriculture at present is about 2–3 times smaller as it was in the period of collective and state farms in 1980s. Similar to fertilizers the use of pesticides depends on

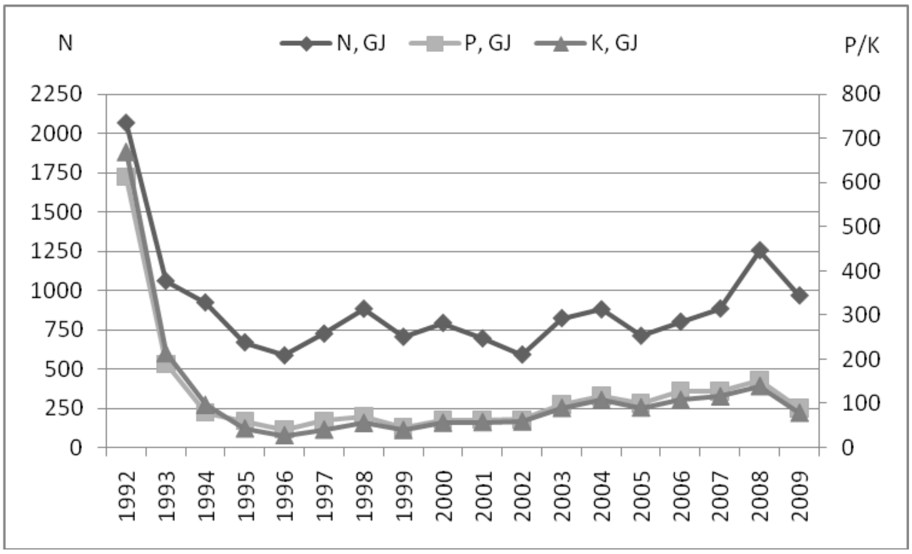

Figure 7.5: Mineral fertilizer nutrient use dynamics in Estonian agriculture 1992...2009, GJ Source data: Statistics Estonia, 2010

market situation, also from legislative regulation. High input prices and low buying-up prices probably caused decrease in use of pesticides since 2007.

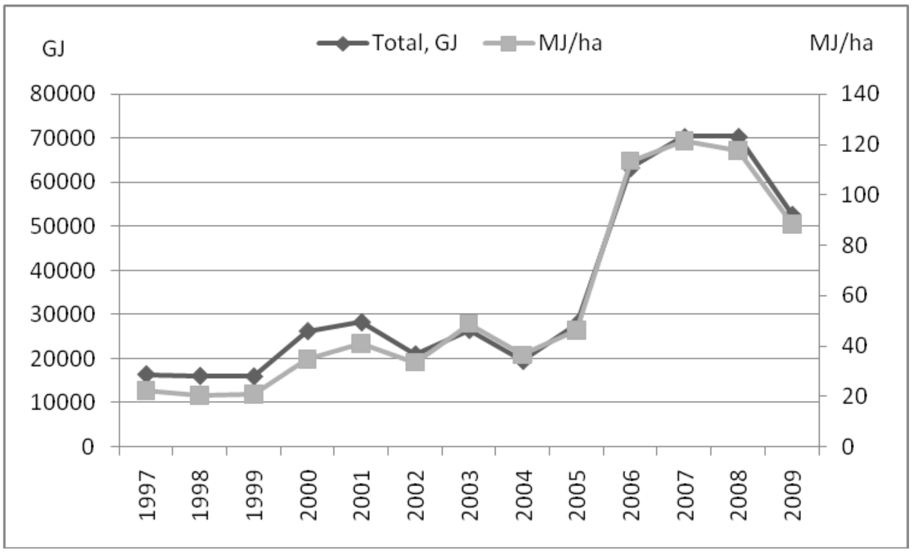

Figure 7.6: Use of plant protection (herbicides, fungicides and insecticides) agents 1997...2009 Source data: Statistics Estonia, 2010

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